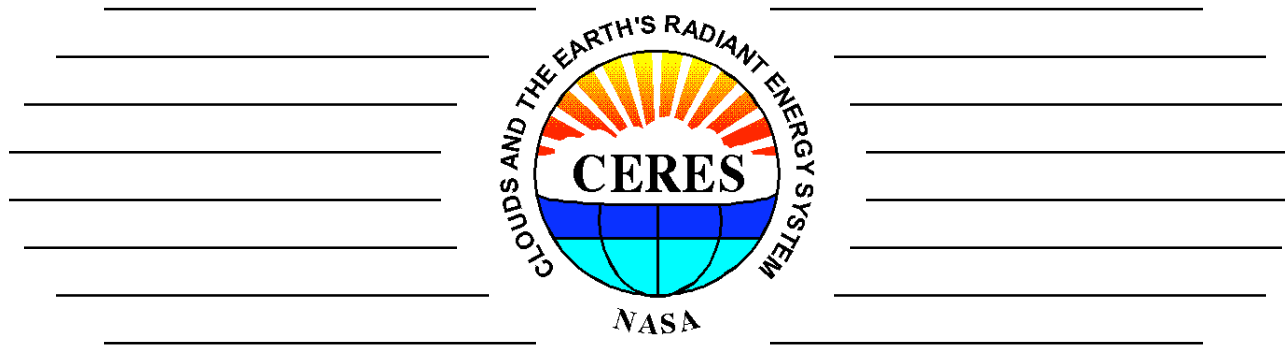


# Terra/Aqua Instrument Calibration Report

## Edition 3 Status

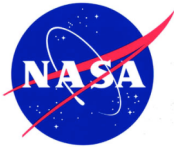


**Kory J. Priestley**  
**Susan Thomas, Denise Cooper,**  
**Phil Hess, Grant Matthews, Peter Szewczyk,**  
**Dale Walikainen, Robert Wilson**

**CERES Science Team Meeting**

Newport News, VA

April 24  
-26, 2007



NASA Langley Research Center

**Atmospheric**  
SCIENCES

# CERES Instrument Working Group Homepage



The screenshot shows the homepage of the CERES Instrument Working Group. At the top, the title "INSTRUMENT WORKING GROUP" is displayed in large white letters, with the subtitle "CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM" below it. A navigation bar contains links: Introduction, Activities, Documentation, Operations, Production, Data, and Personnel. The main content area is divided into two sections. On the left, a large image of the CERES instrument on the Earth Radiation Budget Experiment (ERBE) satellite is shown, with the text "SITE INDEX" below it. On the right, the "OPERATIONS" section lists various links: Daily Statistics (PFM, FM1, FM2, FM3, FM4), Mode Command Logs (PFM, FM1, FM2, FM3, FM4), Daily Mission Modes (TRMM, Terra, Aqua), Instrument Operations (TRMM, Terra, Aqua), HK Trend Plots (Terra, Terra (Edit), Aqua, Aqua (Edit)), Spacecraft Events, and Instrument Coverage Request. At the bottom, there is a copyright notice for NASA Langley Research Center, a last updated date of Fri Aug 27 2004 16:29:11, a web curator Phil Hess (p.c.hess@larc.nasa.gov), and a NASA responsible official Kory Priestley (k.j.priestley@larc.nasa.gov). There are also links to the NASA Privacy Statement and Feedback on Langley Products and Services. The NASA Langley Research Center logo is in the bottom left, and the CERES logo is in the bottom right.

**INSTRUMENT WORKING GROUP**  
CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM

[Introduction](#) [Activities](#) [Documentation](#) [Operations](#) [Production](#) [Data](#) [Personnel](#)

**OPERATIONS**

Daily Statistics: [PFM](#) [FM1](#) [FM2](#) [FM3](#) [FM4](#)

Mode Command Logs: [PFM](#) [FM1](#) [FM2](#) [FM3](#) [FM4](#)

Daily Mission Modes: [TRMM](#) [Terra](#) [Aqua](#)

Instrument Operations: [TRMM](#) [Terra](#) [Aqua](#)

HK Trend Plots:  
[Terra](#) [Terra \(Edit\)](#)  
[Aqua](#) [Aqua \(Edit\)](#)

[Spacecraft Events](#)

[Instrument Coverage Request](#)

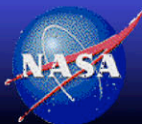
**SITE INDEX**

**Langley Research Center**

© NASA Langley Research Center  
Last Updated: Fri Aug 27 2004 16:29:11  
Web Curator: Phil Hess (p.c.hess@larc.nasa.gov)  
NASA Responsible Official: Kory Priestley (k.j.priestley@larc.nasa.gov)  
[NASA Privacy Statement](#) [Feedback on Langley Products and Services](#)

**CERES**

<http://asd-www.larc.nasa.gov/Instrument>



NASA Langley Research Center / Science Directorate

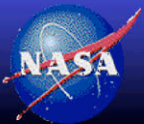


# Progress

---

**prog·ress** (prŏ'rĕ', -rə, prō'grĕ') *n.*

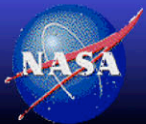
1. Movement, as toward a goal; advance.
2. Development or growth: *students who show progress.*
3. Steady improvement, as of a society or civilization: *a believer in human progress.* See synonyms at [development](#).
4. A ceremonial journey made by a sovereign through his or her realm.



# Agenda

---

- **Summary of Edition3 Philosophy**
  - **Major Modifications to CalVal Algorithms**
- **Provide a status of the BDS and ERBE Like Data Products**
  - **Edition 3 vs. Edition2\_Rev1**
- **Detailed discussion of Edition3 algorithm modifications.**



**NASA Langley Research Center / Science Directorate**

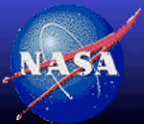




# Questions and Comments for thought

---

1. In Edition3 does the Science Team want all of the CERES instruments placed on the same radiometric scale?
2. Is the Science Team comfortable with using Deep Convective Clouds as a relative calibration target?



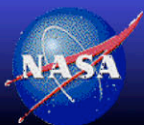
NASA Langley Research Center / Science Directorate



# CERES Terra/Aqua Health & Status

**With the exception of the SW channel on the CERES/Aqua FM-4 Instrument, the CERES Terra/Aqua instruments are functioning nominally...**

Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	85 +
Aqua	FM3, FM4	5/02	6/02	58 +
-	FM5	-	-	-

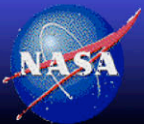


# CERES Terra/Aqua Health & Status

With the exception of the SW channel on the CERES/Aqua FM-4 Instrument, the CERES Terra/Aqua instruments are functioning nominally...

Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	85 +
Aqua	FM3, FM4	5/02	6/02	58 +
<b><i>NPP</i></b>	FM5	<b><i>9/09</i></b>	-	-

**24 + Instrument Years of Data**



NASA Langley Research Center / Science Directorate



# Instrument Artifact Removal Strategy

---

Remote sensing instruments generally exhibit time varying artifacts in their data products. For CERES these artifacts stem predominantly from either of 2 physical entities.....

- **Radiometric Gain Change**
  - Wavelength independent change in sensor responsivity
  - Corrections implemented in Count Conversion algorithm (SS1)
- **Spectral Response Change**
  - Wavelength dependent change in sensor optics
  - Corrections implemented in Spectral Unfiltering algorithms (SS2)

Radiometric Channel	Spectral Region	
	SW	LW
Total	<3.0 um	>3.0 um
SW	<5.0 um	-
WN	-	8-12 um



# BDS and ERBE-Like Release Strategy

---

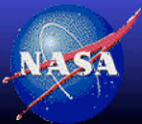
**Edition1 - Static Algorithms and coefficients - baseline product used in cal/val protocol**

**Edition2 - Utilizes temporally varying coefficients to correct for traceable radiometric drift. All spectral changes are broadband and 'gray'.**

**Edition3 - Delivery date Summer 2007. Will incorporate temporally varying spectral artifacts in the SW measurements. A complete re-analysis of Ground Calibration with additional component characterization measurements.**

**User Applied Revisions - Advance capabilities to the users prior to the release of the next Edition.**

**Edition2 products lag Edition1 by a minimum of 4 months**



NASA Langley Research Center / Science Directorate

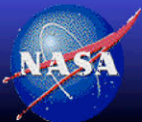


# CERES Unfiltered Radiance Summary

- Cal/Val Protocol demonstrates radiometric stability of the data products through 12/2005 of....

	Edition1				Edition2				Edition2_Rev1				Edition 3 (Anticipated)			
	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4
LW <sub>day</sub>	.3	.6	.4	.4	.125	.125	.3	.3	.125	.125	.15	.15	<.1	<.1	<.1	<.1
LW <sub>night</sub>	.1	.125	.125	.125	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	<.1	<.1
SW	.2	.4	.4	.5	.2	.3	.3	.4	<.1	<.1	.25	.25	<.1	<.1	<.1	<.1
WN	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	<.1	<.1

Note: Values apply to all-sky global averages  
Units are in %/yr



NASA Langley Research Center / Science Directorate

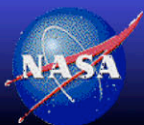


# CERES Unfiltered Radiance Summary

- Cal/Val Protocol demonstrates radiometric stability of the data products through 12/2005 of....

	Edition1				Edition2				Edition2_Rev1				Edition 3 (Anticipated)			
	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4	FM1	FM2	FM3	FM4
LW <sub>day</sub>	.3	.6	.4	.4	.125	.125	.3	.3	.125	.125	.15	.15	<.1	<.1	<.1	<.1
LW <sub>night</sub>	.1	.125	.125	.125	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	<.1	<.1
SW	.2	.4	.4	.5	.2	.3	.3	.4	<.1	<.1	.25	.25	<.1	<.1	<.1	<.1
WN	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	.1	.1	<.1	<.1	<.1	<.1

Note: Values apply to all-sky global averages  
Units are in %/yr



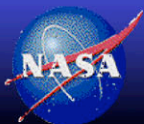
NASA Langley Research Center / Science Directorate



# CERES BDS and ERBE-Like Product Status

Spacecraft	Product	Version	Available	Months Processed
TRMM	BDS	Edition1	Yes	1/98 - 8/98 , 3/00
	ERBE-Like	Edition1	Yes	1/98 - 8/98 , 3/00
		Edition2	Yes	1/98 - 8/98 , 3/00
Terra	BDS	Edition1	Yes	2/00 - present
		Edition2	Yes	2/00 - <b>12/06</b>
	ERBE-like	Edition1	Yes	2/00 - present
		Edition2	Yes	2/00 - <b>12/06</b>
Aqua	BDS	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 - <b>12/06</b>
	ERBE-like	Edition1	Yes	6/02 - present
		Edition2	Yes	6/02 - <b>12/06</b>

Note: **Red** text indicates months are in final validation prior to public release.

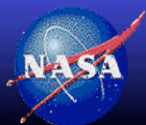
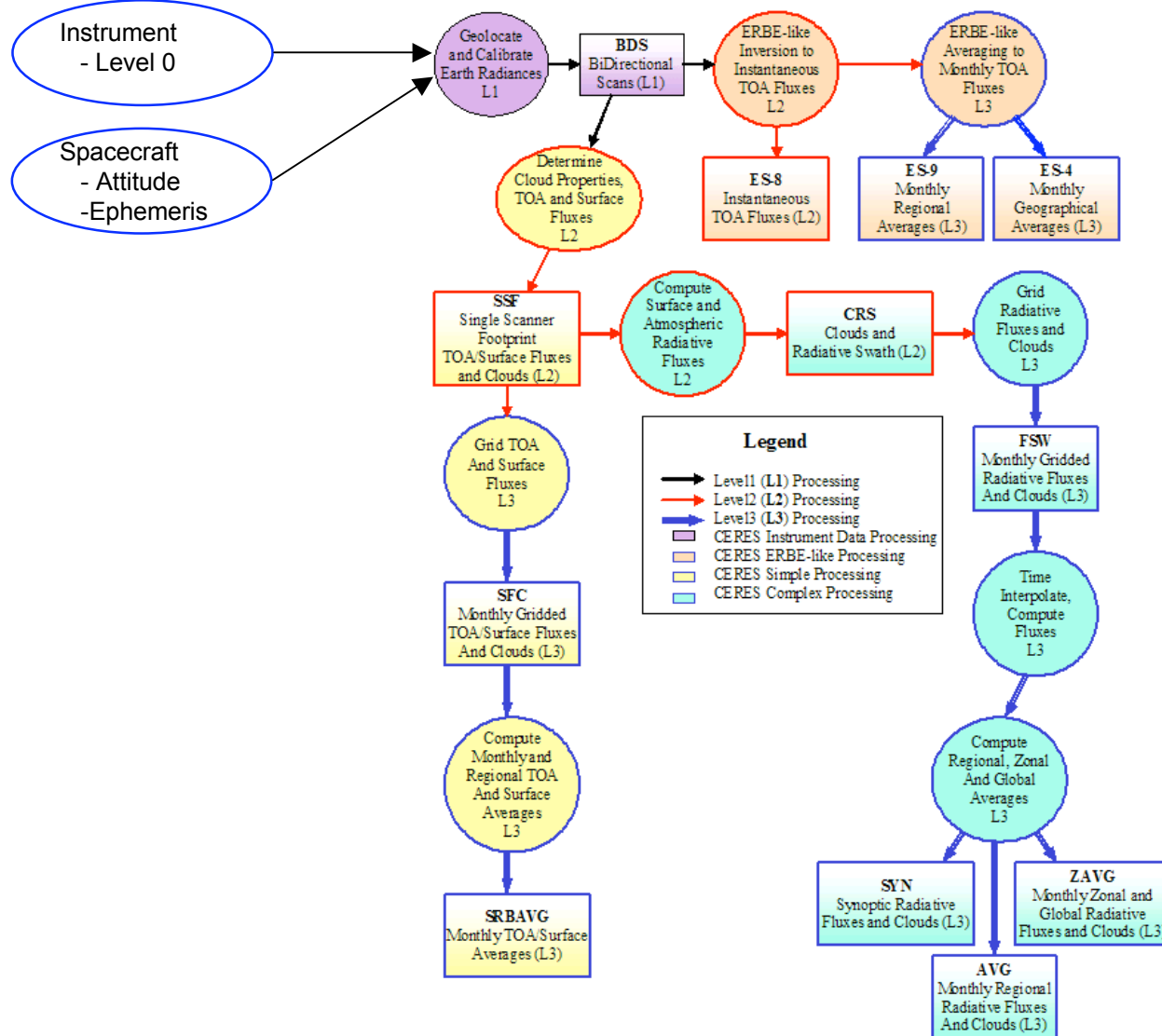


NASA Langley Research Center / Science Directorate





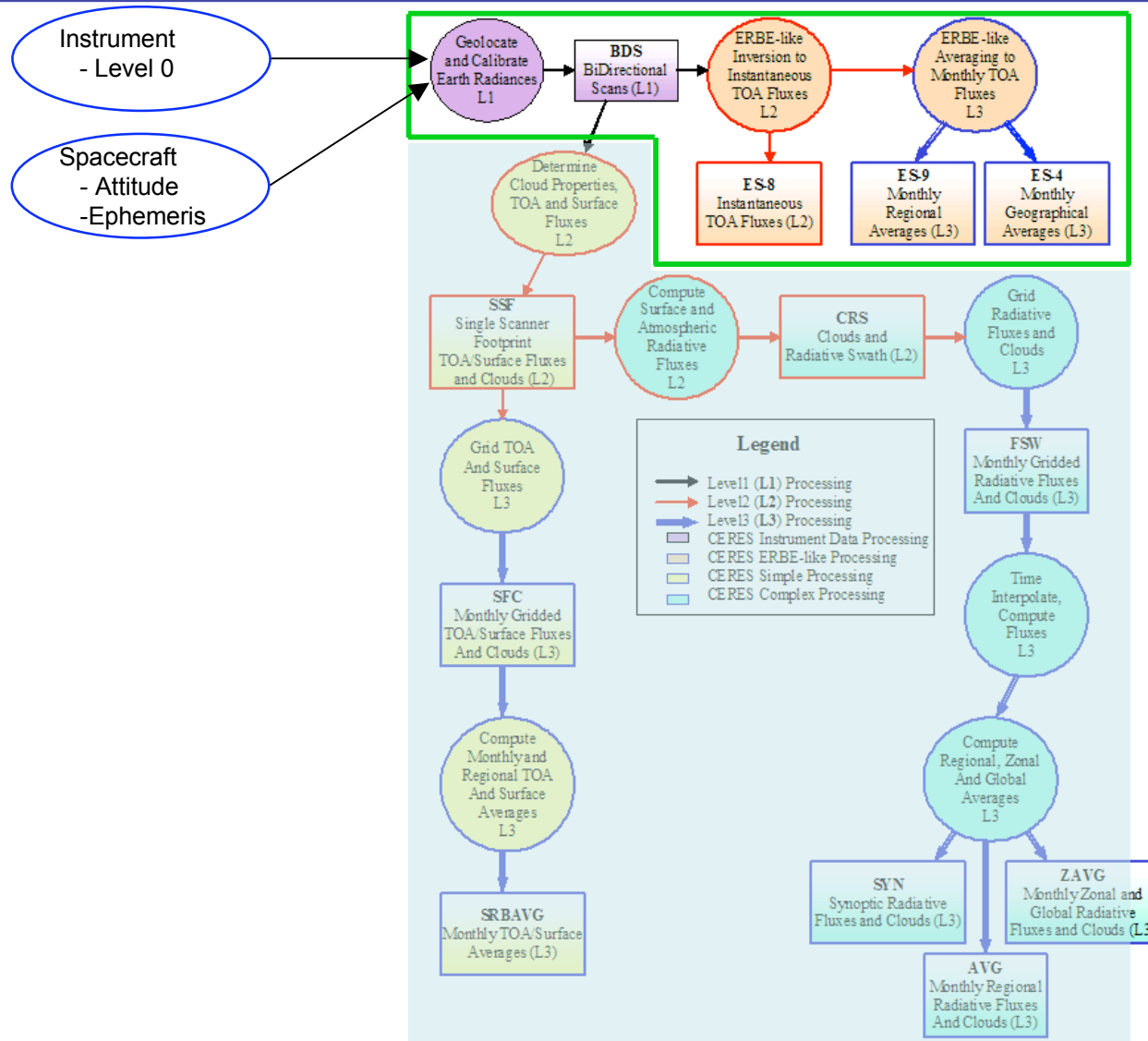
# CERES Data Flow Diagram



NASA Langley Research Center / Science Directorate



# Edition 2 Inputs for Cal Val Protocol



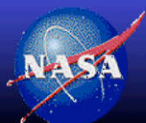
## ERBE-Like

### Advantages

- Availability
- Small Data Volume

### Disadvantages

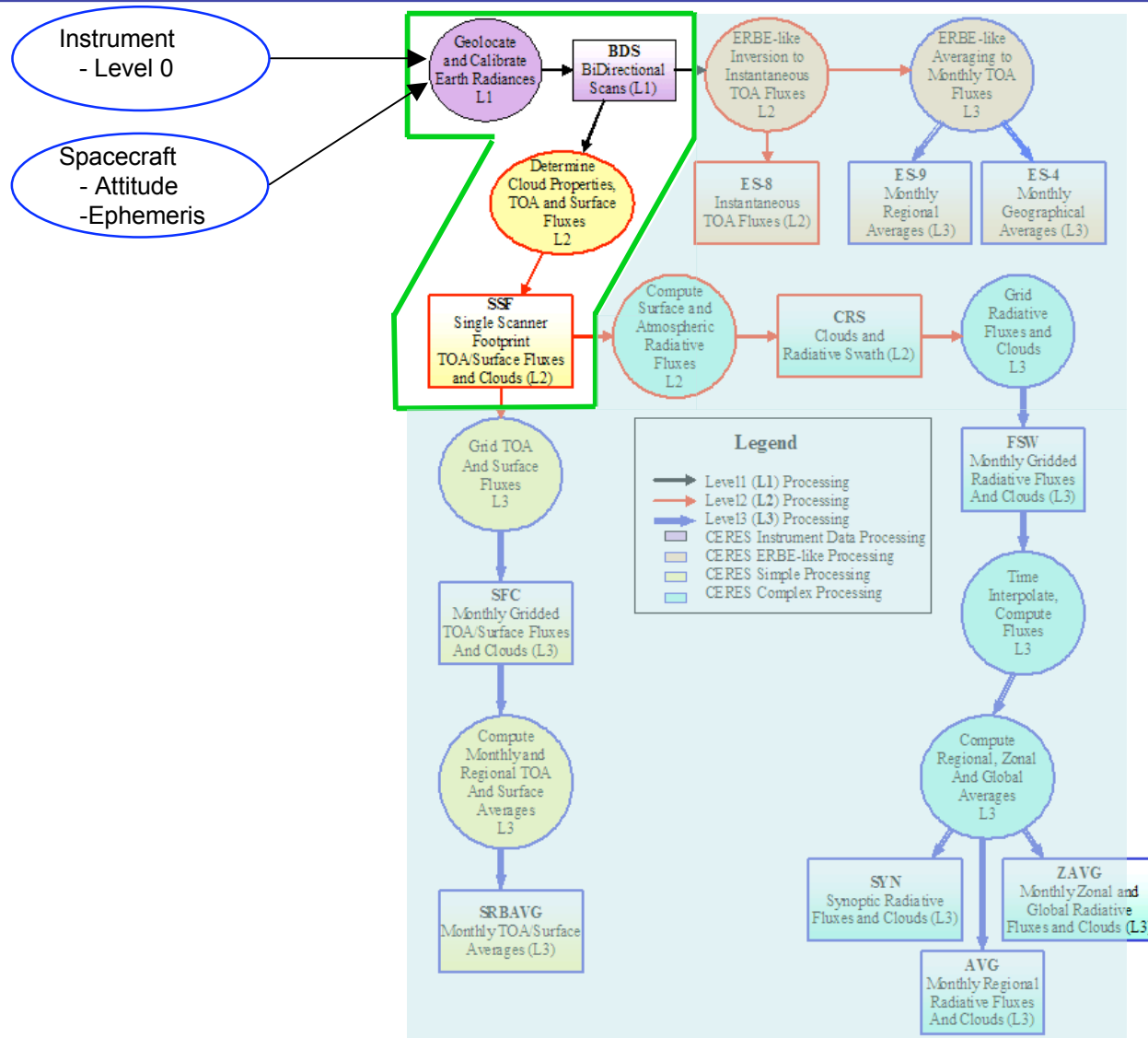
- Inadequate Scene ID



NASA Langley Research Center / Science Directorate



# Edition 3 Inputs for Cal Val Protocol



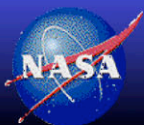
**SSF**

## Advantages

- Full CERES Algorithms
- Improved Scene ID

## Disadvantages

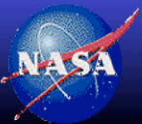
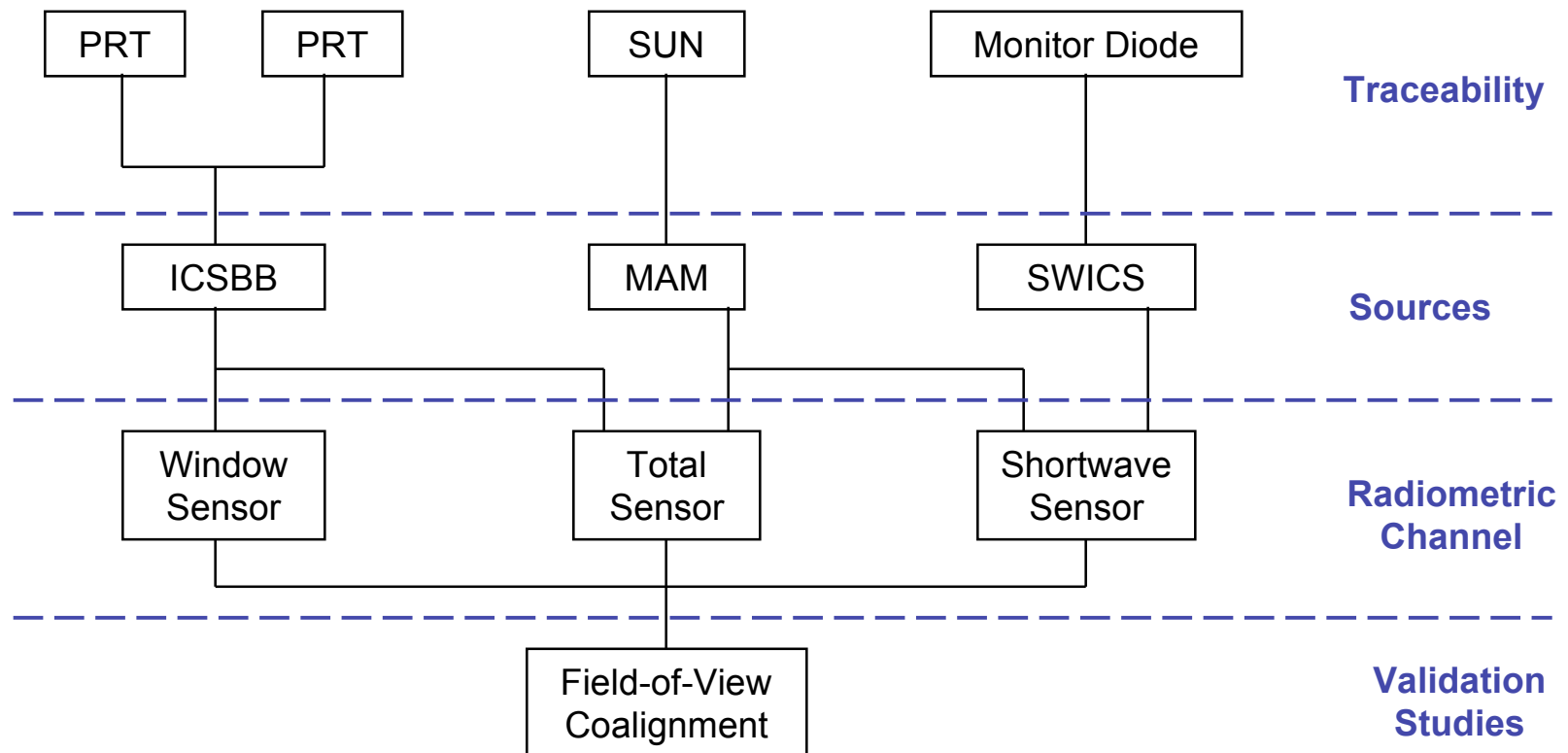
- Availability
- Large Data Volume



NASA Langley Research Center / Science Directorate



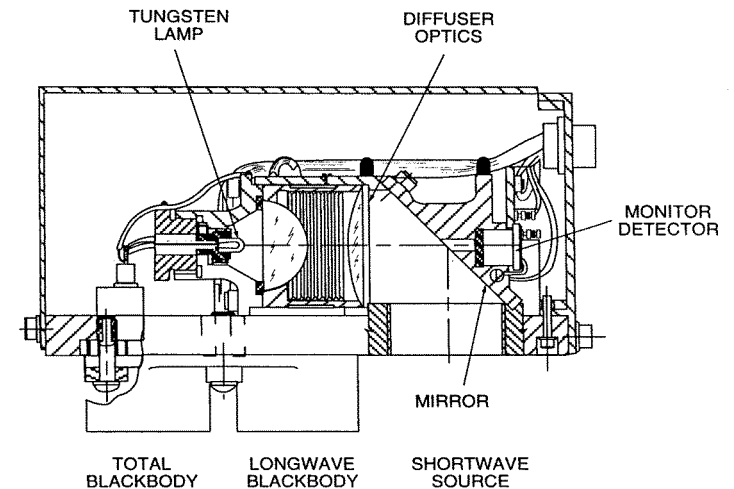
# CERES Onboard SW Calibration Philosophy



# CERES Onboard SW Calibration Equipment

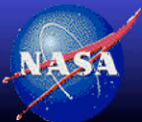
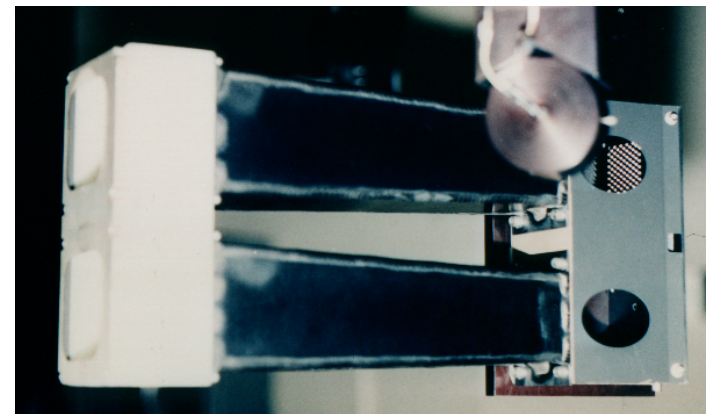
## Shortwave Internal Calibration Source (SWICS)

- Quartz-halogen tungsten lamp (2100, 1900, 1700 K spectrums)
- SiPd independently monitors lamp output
- Design specification is  $\pm 0.5\%$  stability over 5-year mission
- Designed primarily to transfer Ground Calibration measurements into orbit



## Mirror Attenuator Mosaic (MAM)

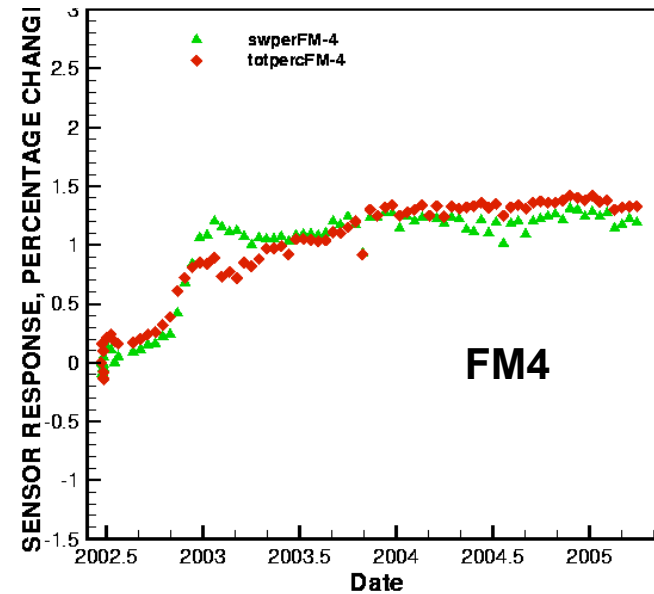
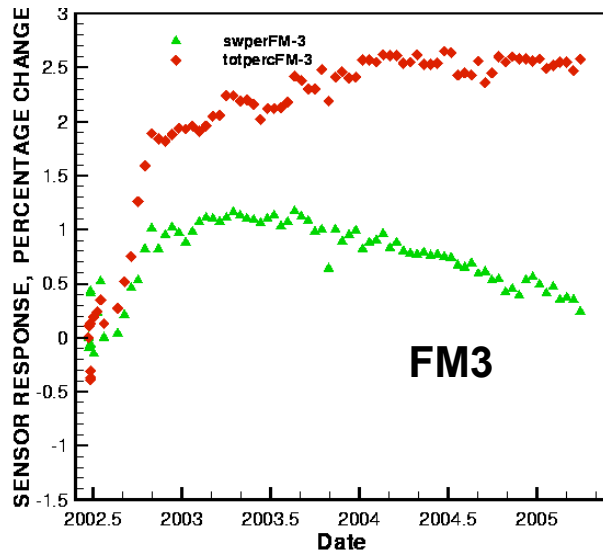
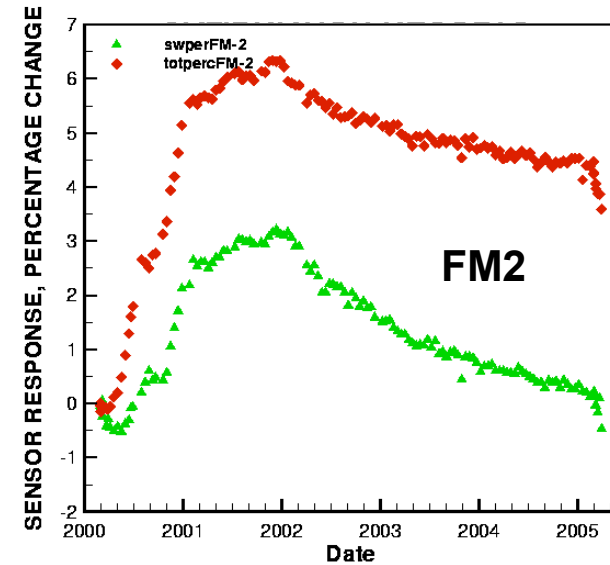
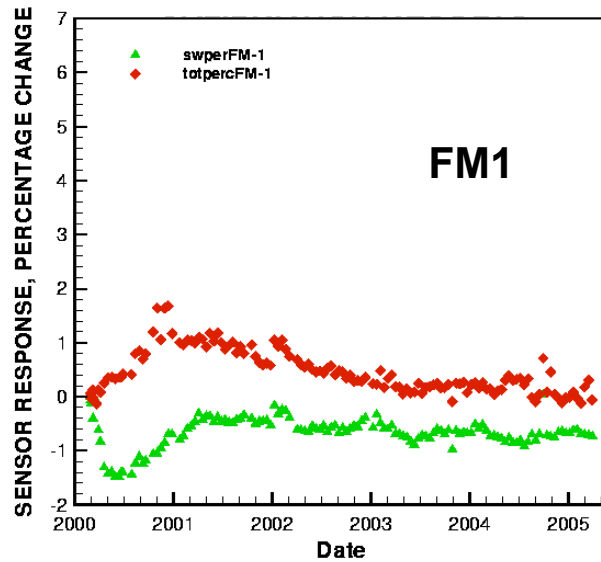
- Solar Diffuser plate attenuates direct solar view (~5800K Spectrum)
- MAM is a Nickel substrate with Aluminum coated spherical cavities or divots
- Provides a Relative calibration of the Shortwave channel and the SW portion of the Total channel
- Designed to provide a long-term on-orbit SW calibration source.
- **Solar Cal results to date are suspect due to large initial drift in MAM surface reflectances...**



NASA Langley Research Center / Science Directorate



# Solar Calibrations

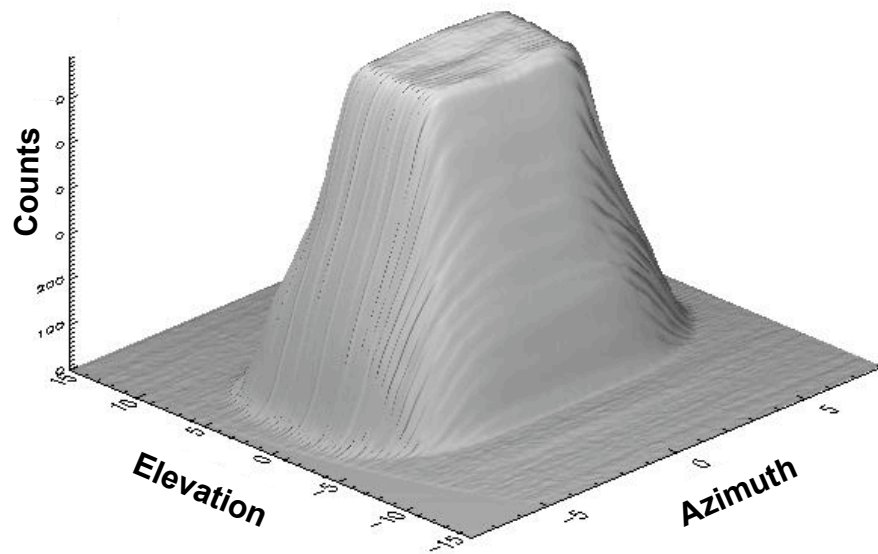


NASA Langley Research Center / Science Directorate

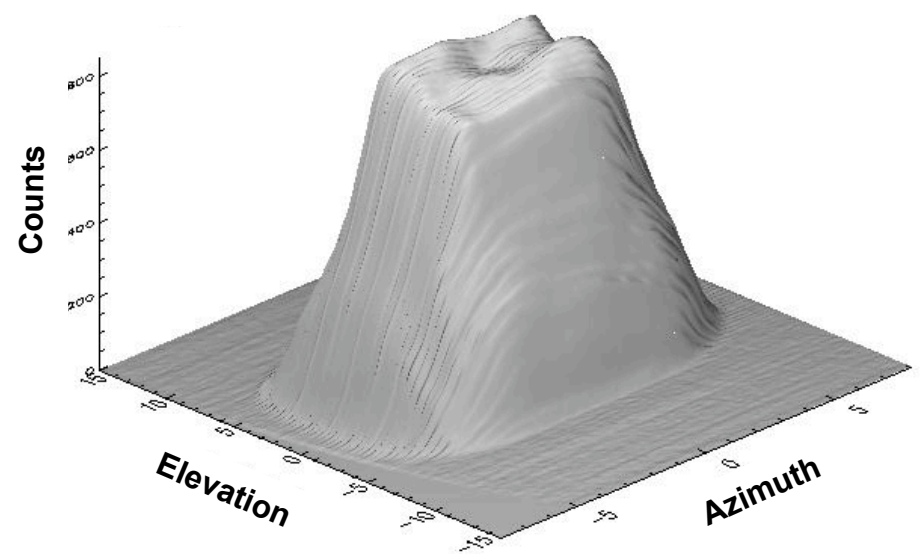


# Modified Solar Cal Procedure Results

Note: Az and El angles are relative to MAM Baffle optical axis

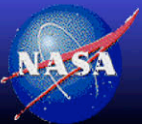


**Total**



**Shortwave**

**FM-1**



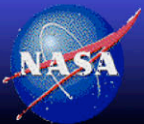
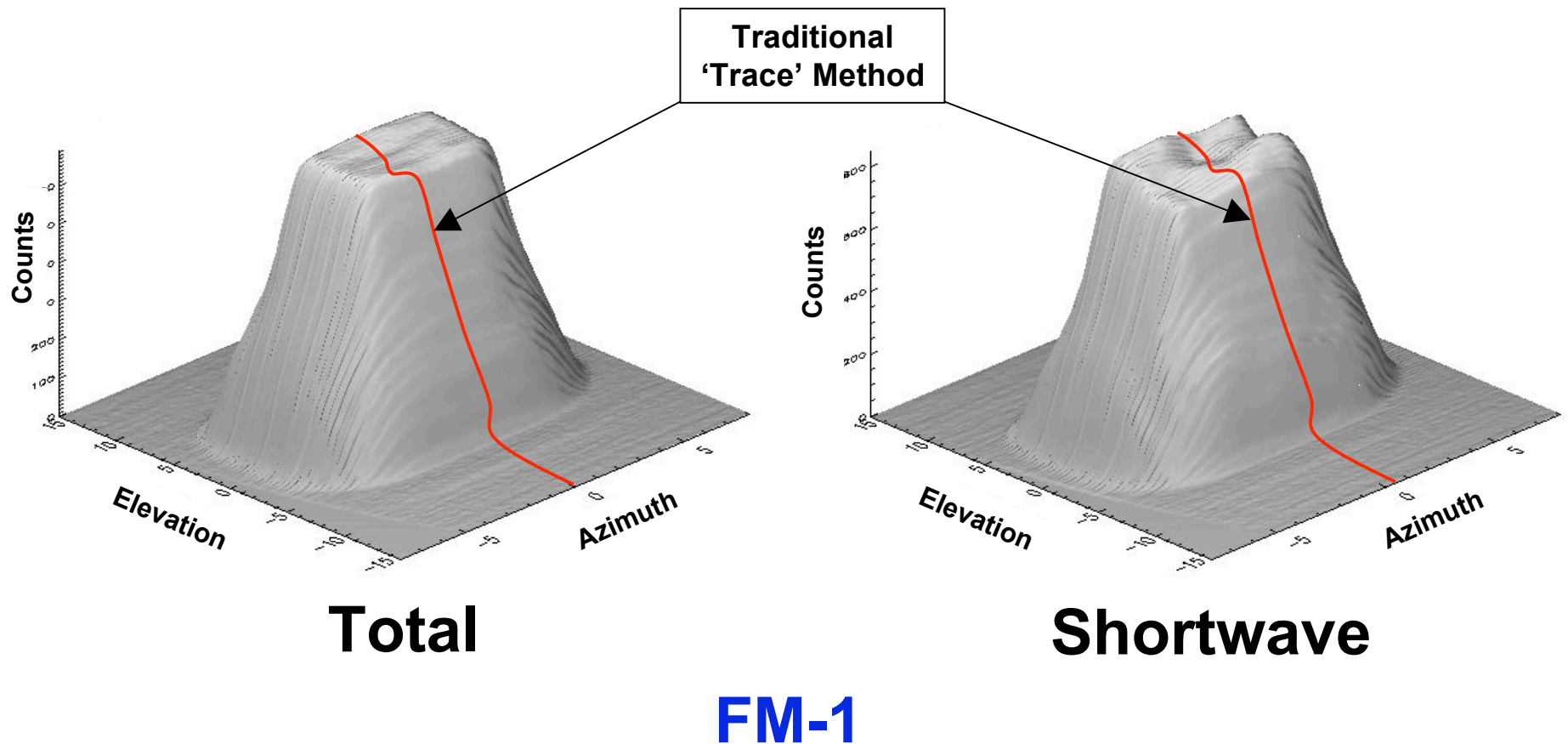
NASA Langley Research Center / Science Directorate





# Modified Solar Cal Procedure Results

Note: Az and El angles are relative to MAM Baffle optical axis

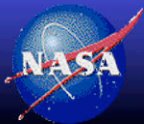
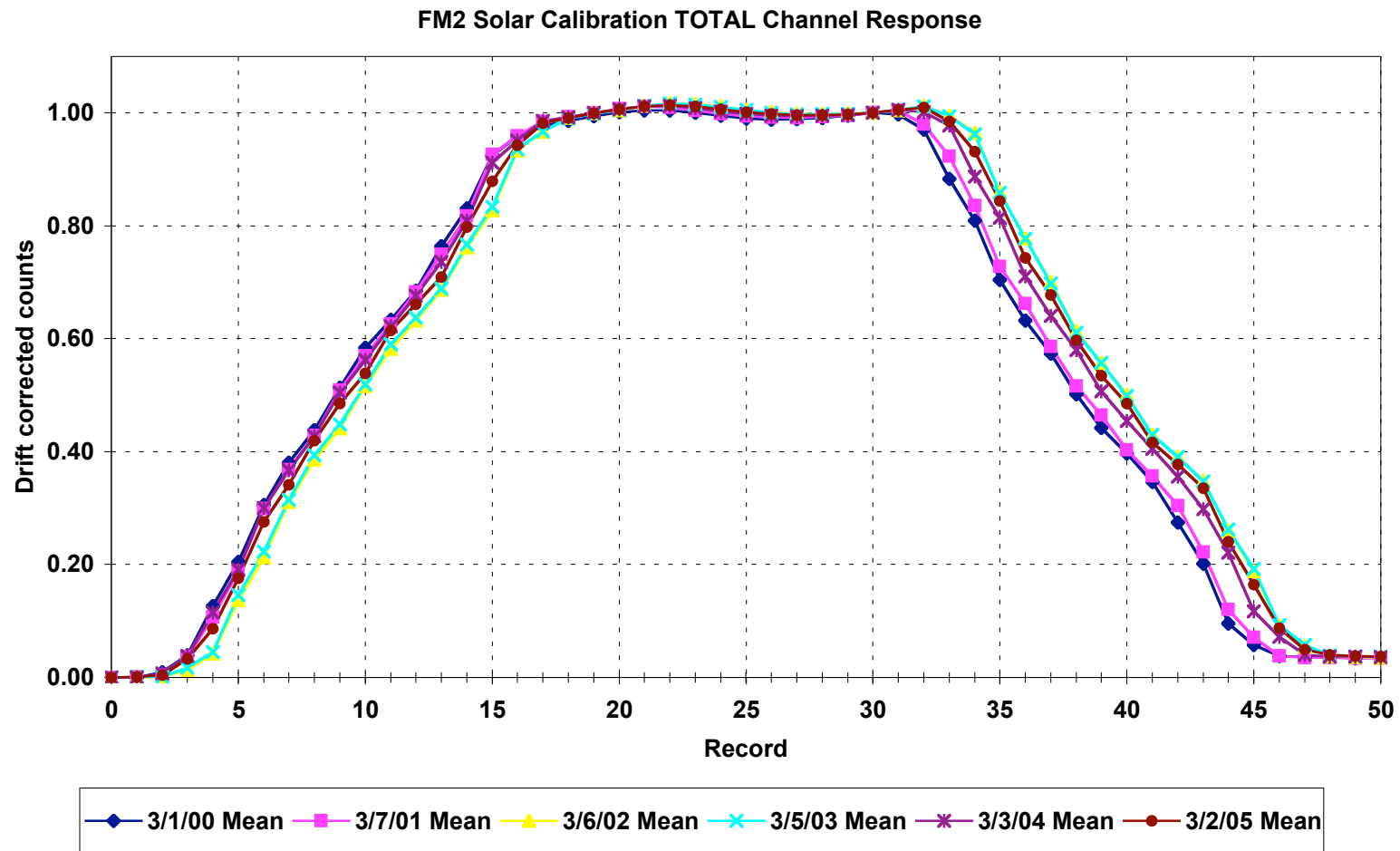


NASA Langley Research Center / Science Directorate





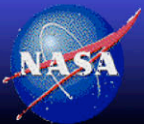
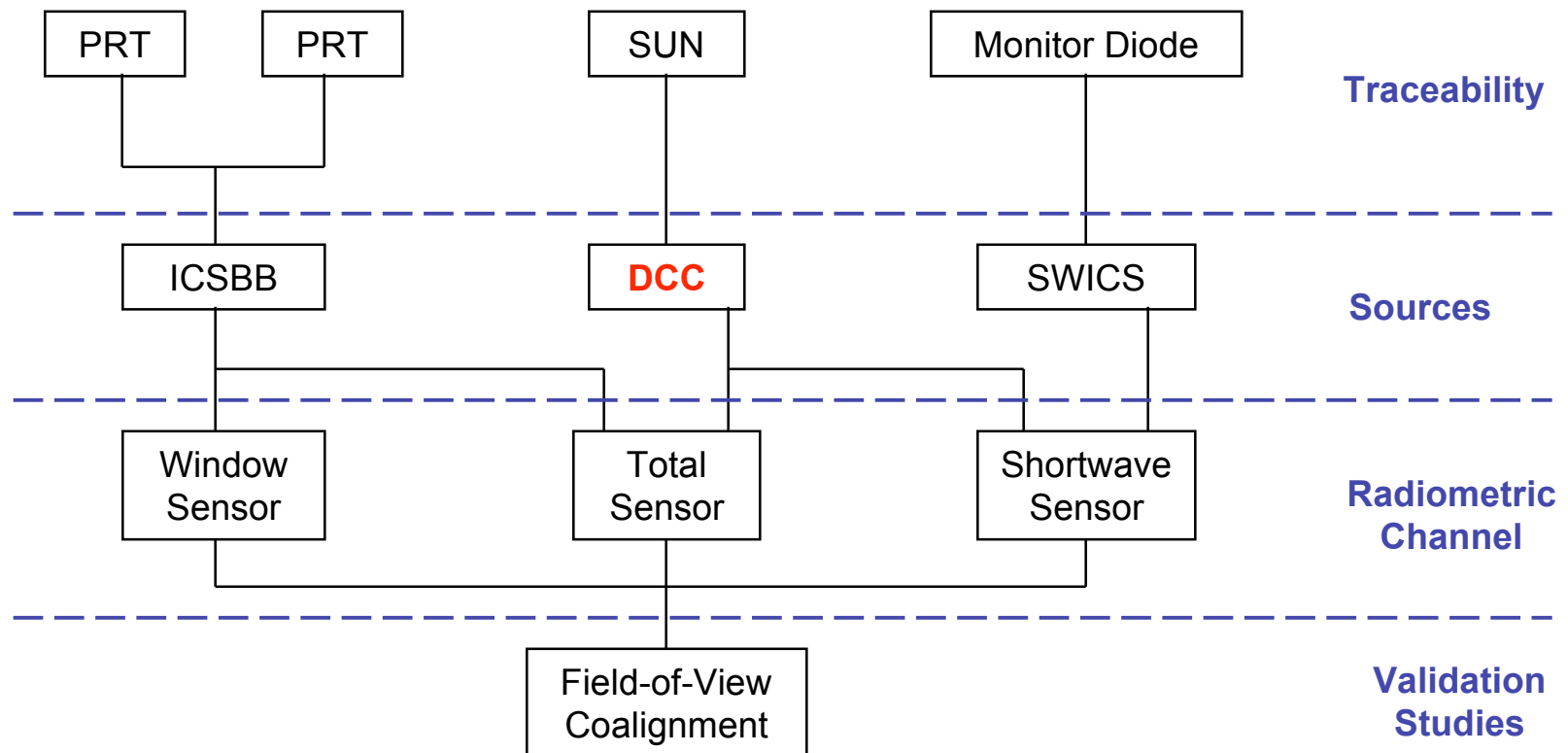
# Solar Calibration Re-Analysis



NASA Langley Research Center / Science Directorate

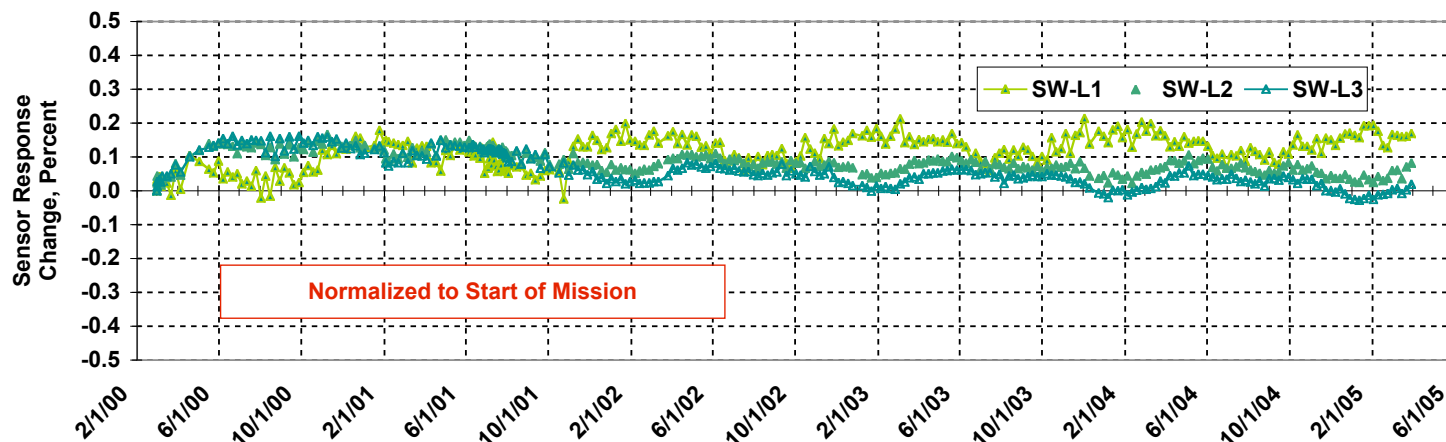


# CERES Onboard SW Calibration Philosophy

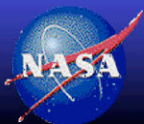
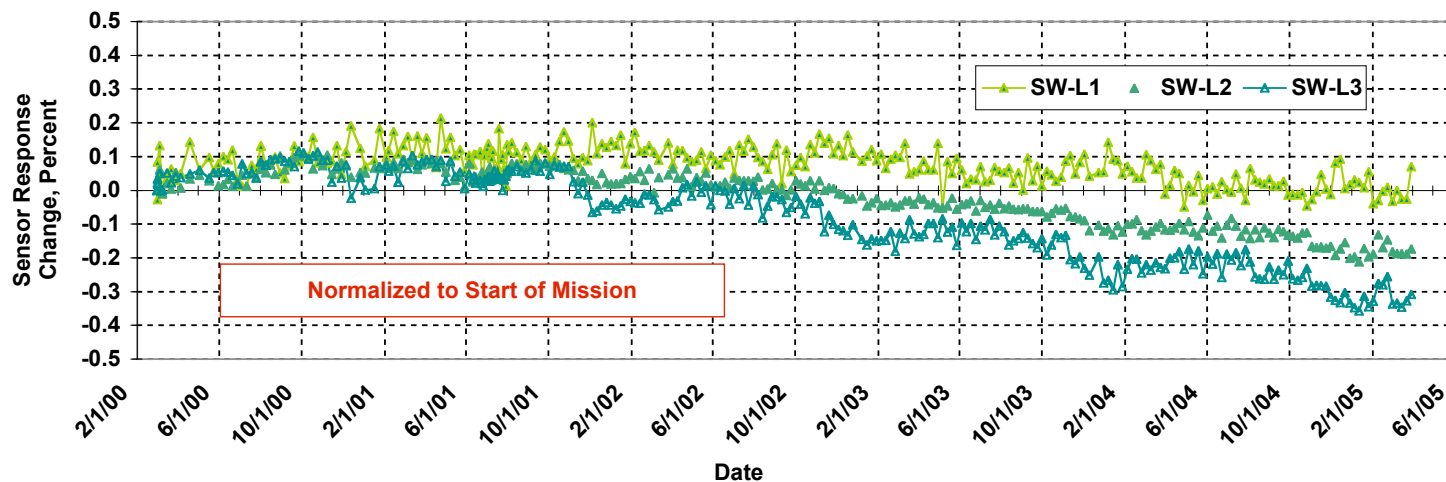


# Terra SW Internal Calibration Results

FM1 In-Flight Internal Calibration Results



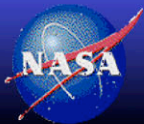
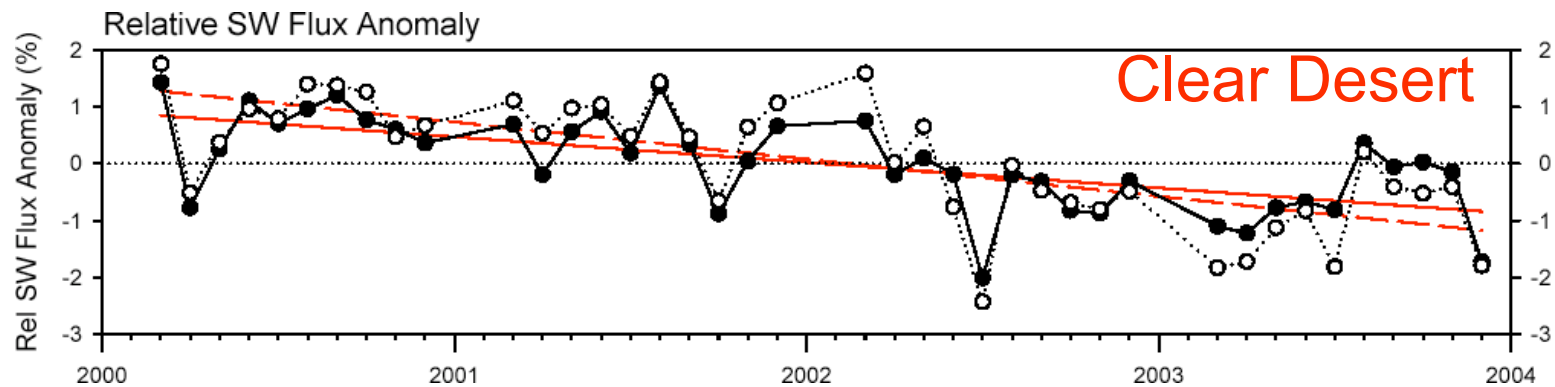
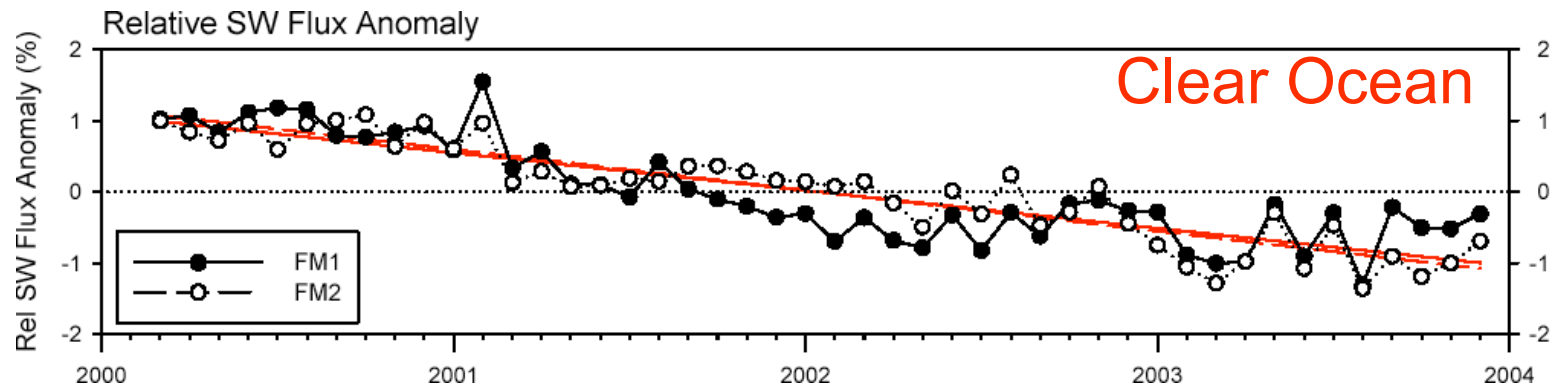
FM2 In-Flight Internal Calibration Results



NASA Langley Research Center / Science Directorate



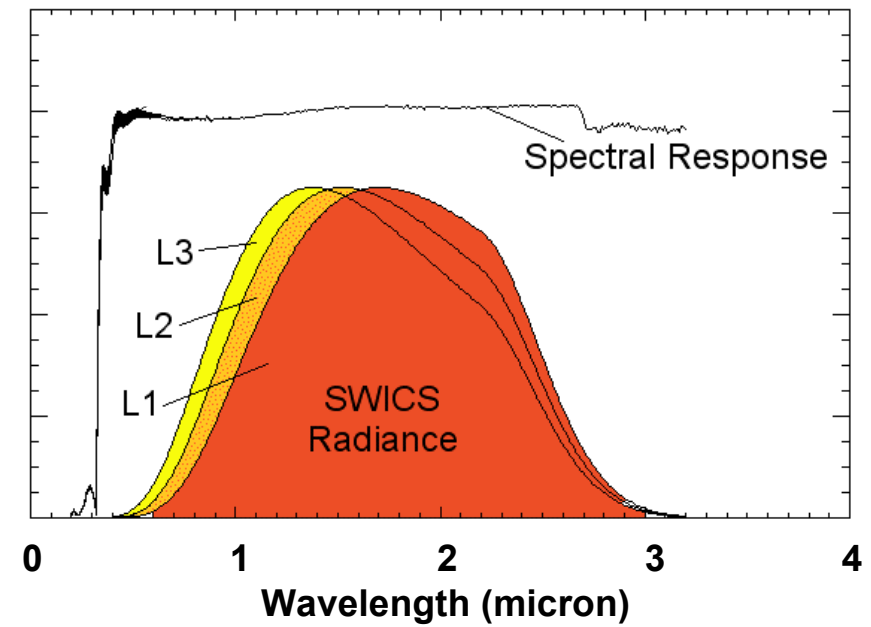
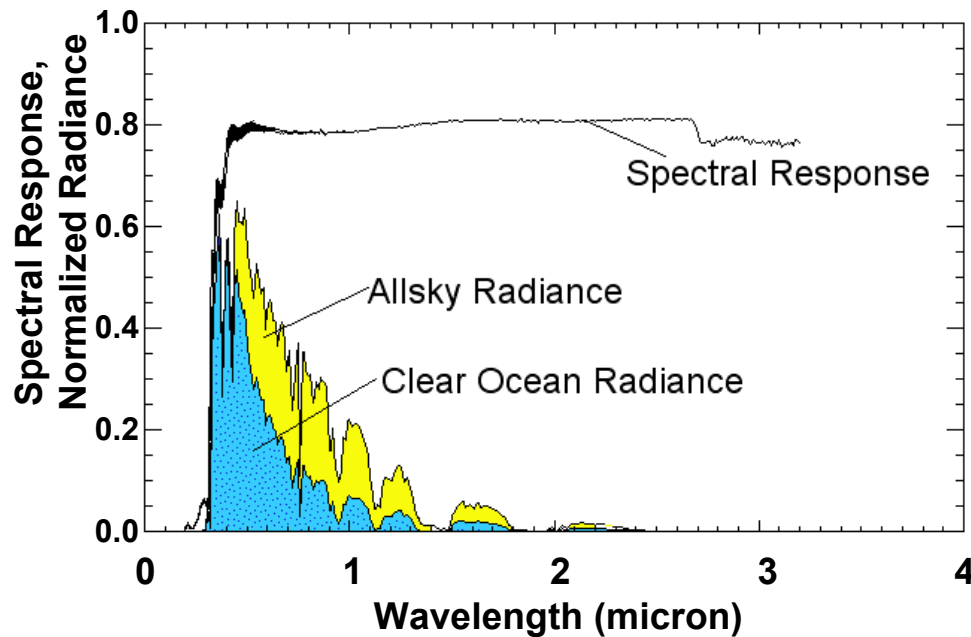
# CERES SSF Ed2B SW TOA Flux Anomaly



NASA Langley Research Center / Science Directorate



# Spectral Degradation : SWICS vs. Earth Spectra



$$f_{allsky}^{sw} \text{ change} \approx -2\%$$

$$f_{swics}^{sw} \text{ change} \approx -0.1\%$$

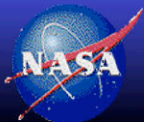
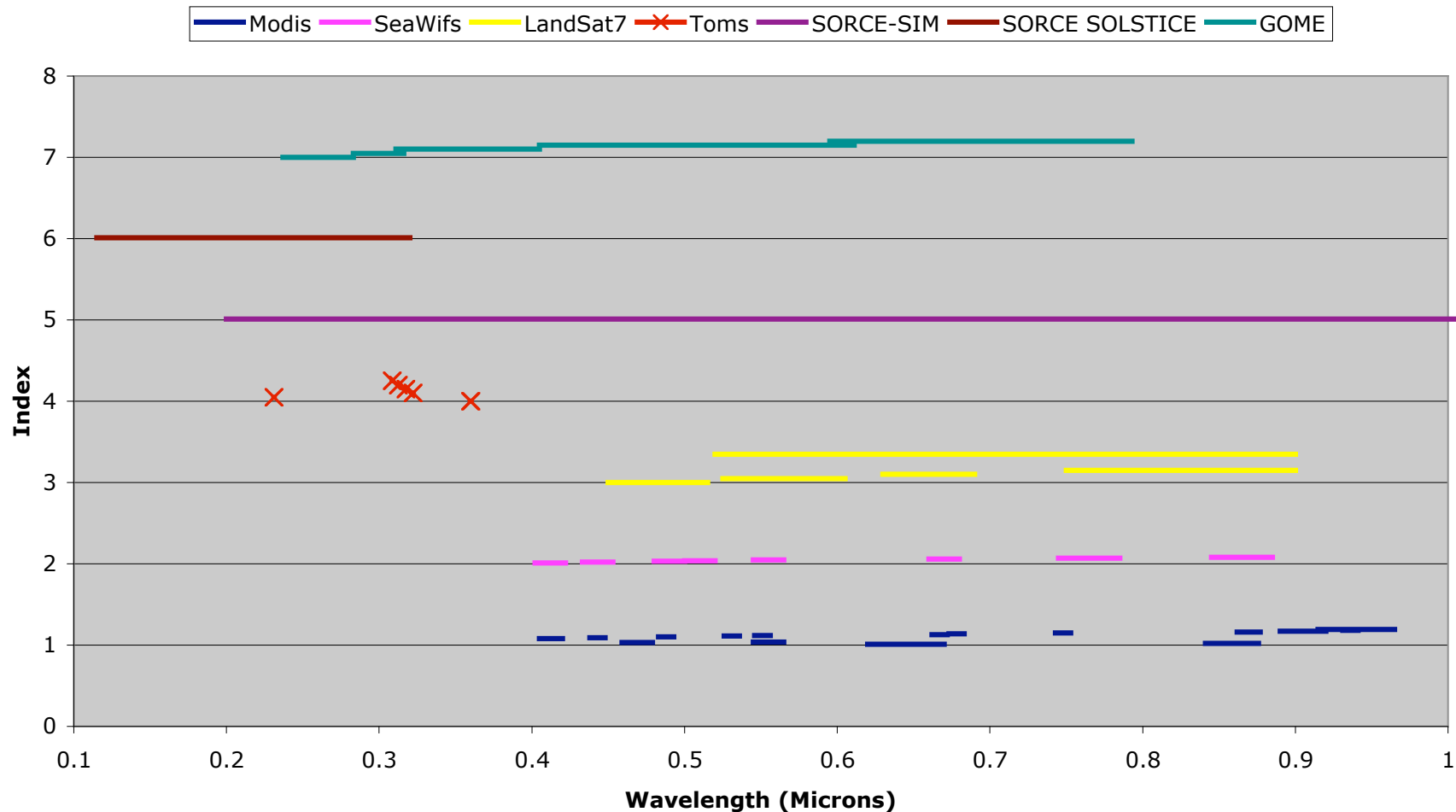


NASA Langley Research Center / Science Directorate



# LEO Missions Subject to Spectral Darkening

## Bandpasses of Selected Instruments

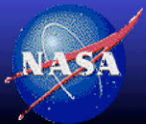
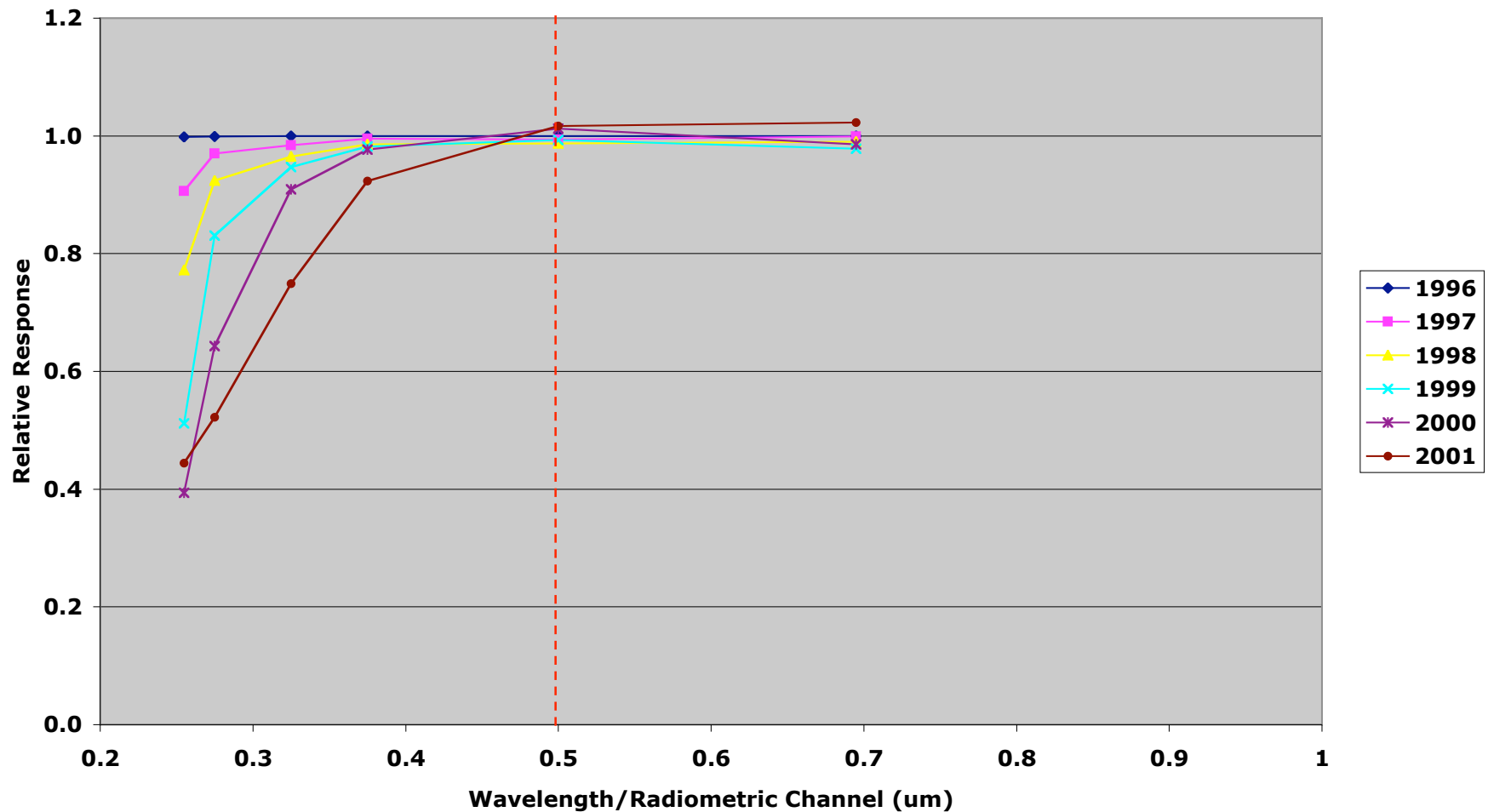


NASA Langley Research Center / Science Directorate



# Spectral Darkening on Similar Missions

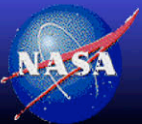
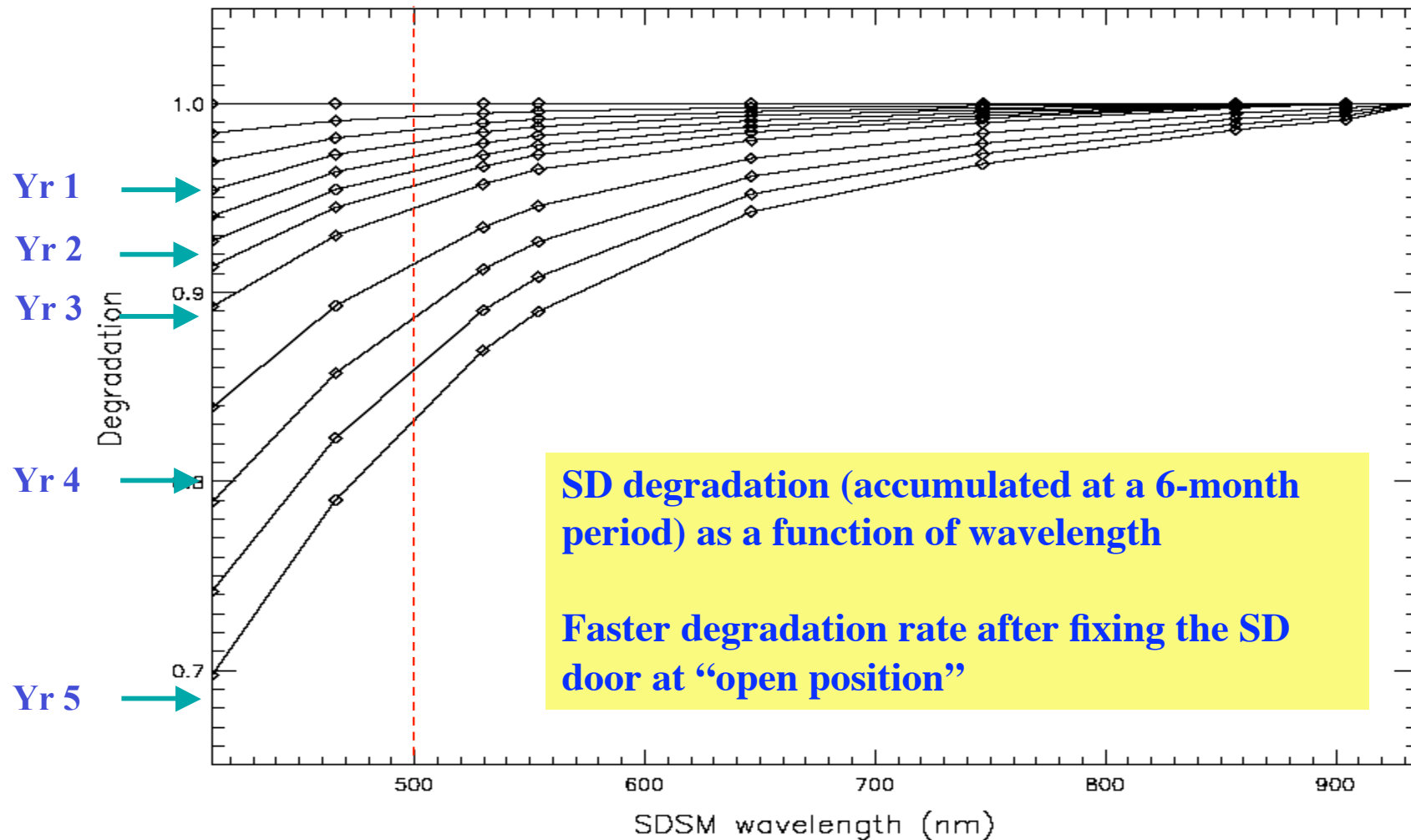
Global Ozone Monitoring Experiment (GOME) Spectral Darkening



NASA Langley Research Center / Science Directorate

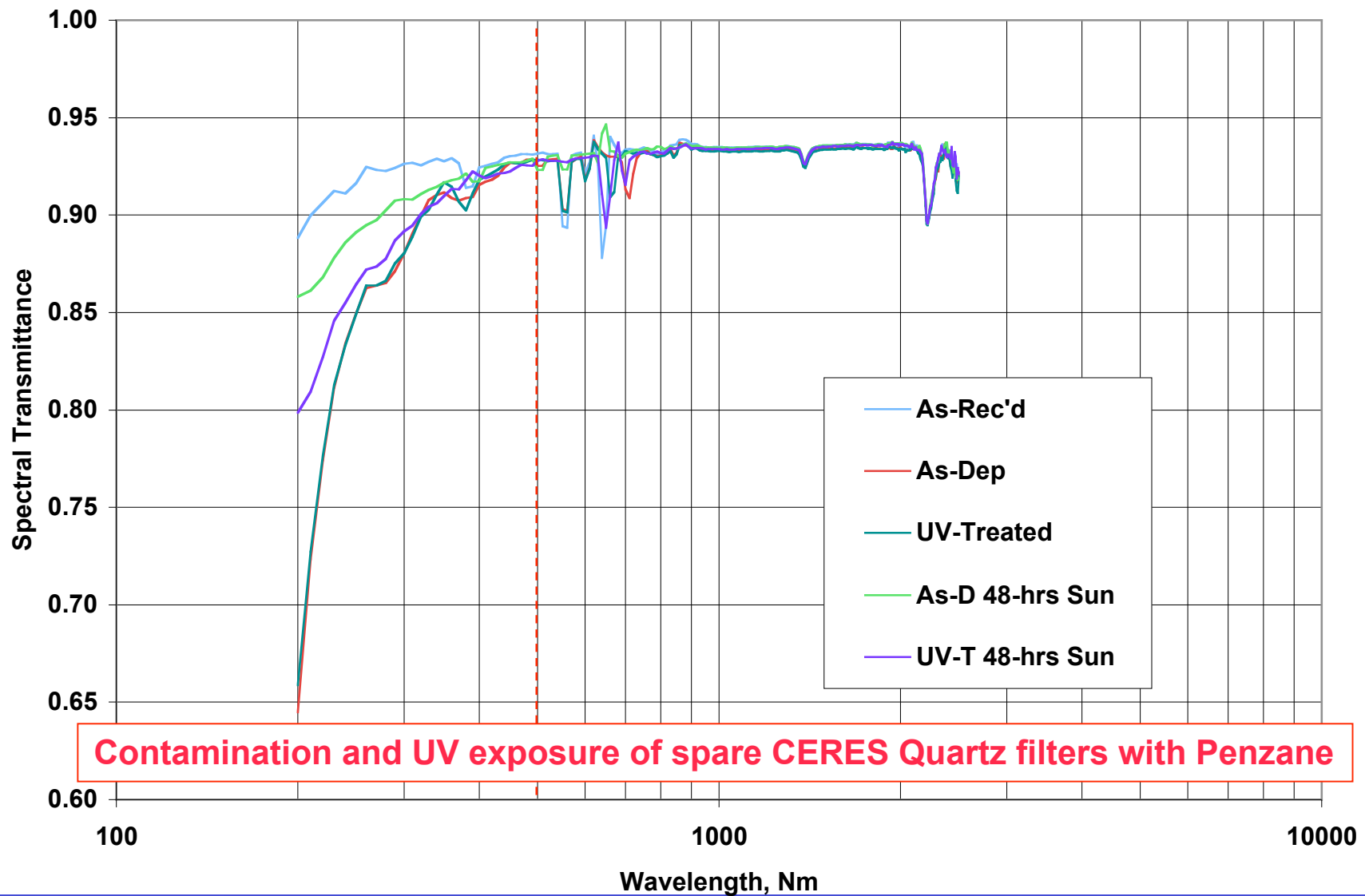


# Modis Solar Diffuser Spectral Degradation

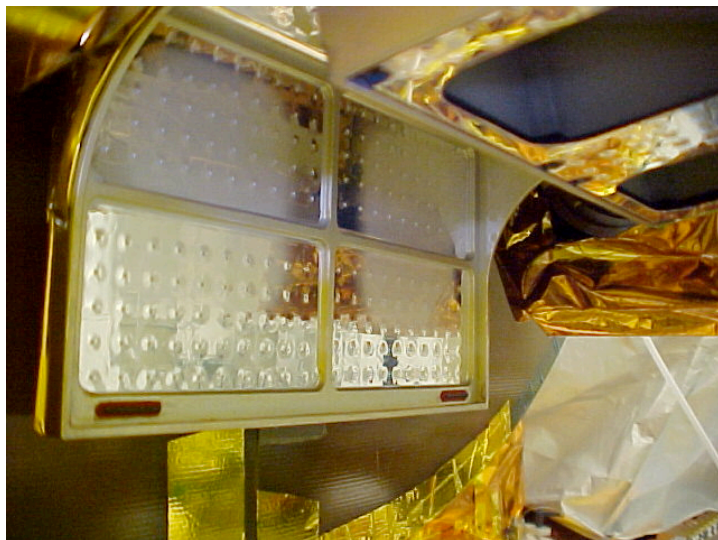
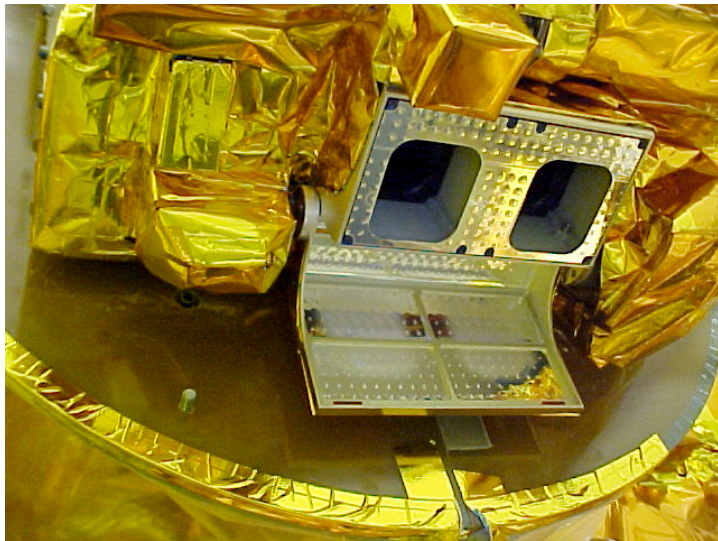




## Preliminary Results of Contamination Study



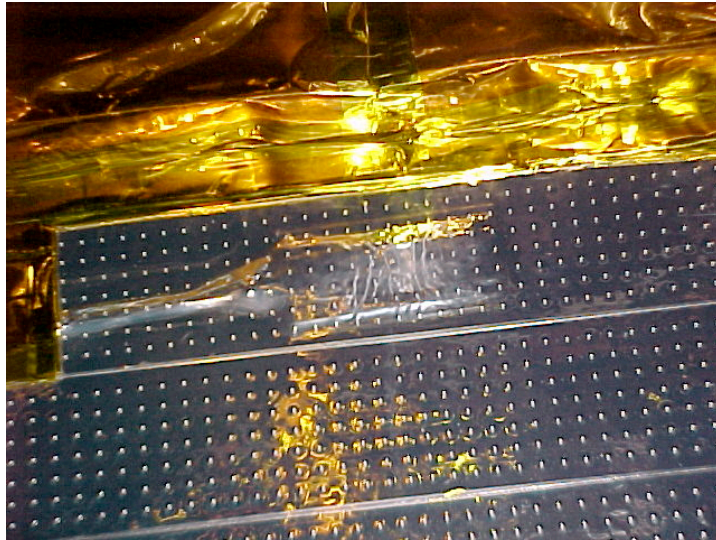
# Foggy Aqua FM-3 MAM Contamination Cover



- Subsequent to spacecraft level thermal vacuum testing, a visual inspection of the FM-3 instrument revealed a 'fog' on the interior surface of the FM-3 MAM contamination cover.
- Visual inspection of optics revealed no visible deposition.
- Testing yielded conflicting opinions of the material, most likely candidate was penzane lubricant.

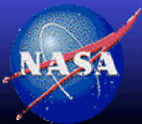


# Burnt CERES Aqua Test Heaters



Prior to spacecraft level thermal vacuum testing, spacecraft personnel overloaded test-only heaters on the CERES Aqua instruments.

Heaters were visibly charred and destroyed. Location is external to optical chamber and under silver teflon radiators. Heaters were removed and area cleaned prior to thermal vac testing.



NASA Langley Research Center / Science Directorate



# **Direct Comparison of Nadir Radiance Measurements**

**Two CERES instruments on a common platform allows for a unique validation opportunity.....**

## **Direct Comparison of simultaneous Nadir measurements**

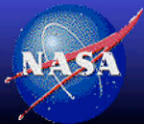
**Each CERES/Terra instrument views nadir every 3.3 seconds**

**Thus, we obtain nearly simultaneous measurements of the same geo-location ( $\Delta t < 3.3$  seconds)....**

**Spatial, angular, and temporal sampling issues are virtually eliminated.**

**26,000 co-located (but not independent) measurements in a given day, provides a very rigorous statistical tool.**

**Results can be discretized by scene type to enhance the analysis.**

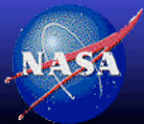
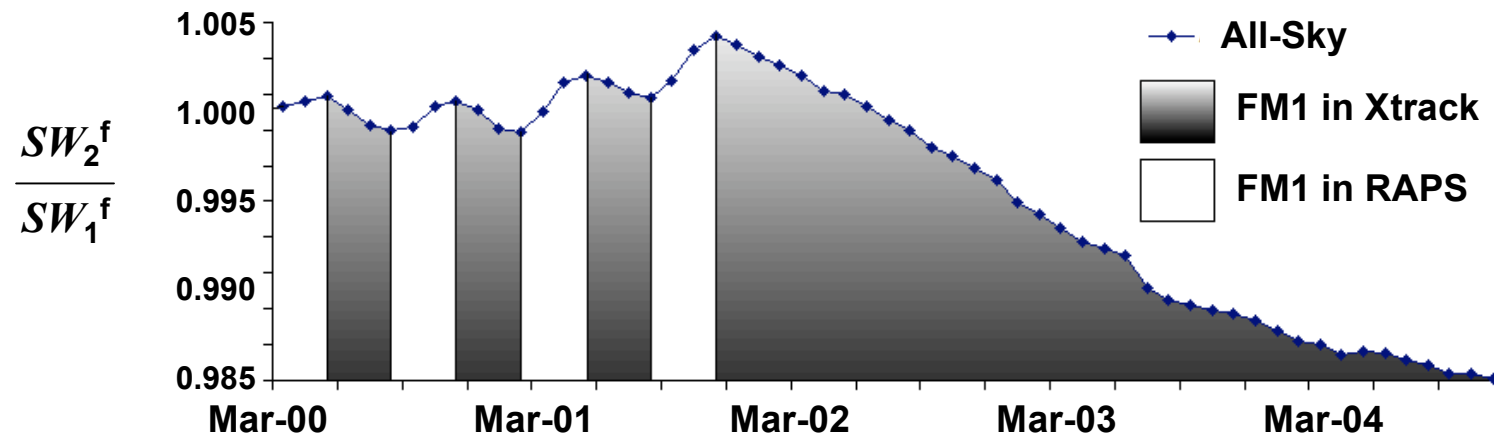


**NASA Langley Research Center / Science Directorate**



# Terra Edition2 Nadir Direct Comparison

## SW Nadir Radiances



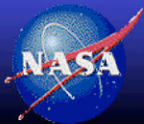
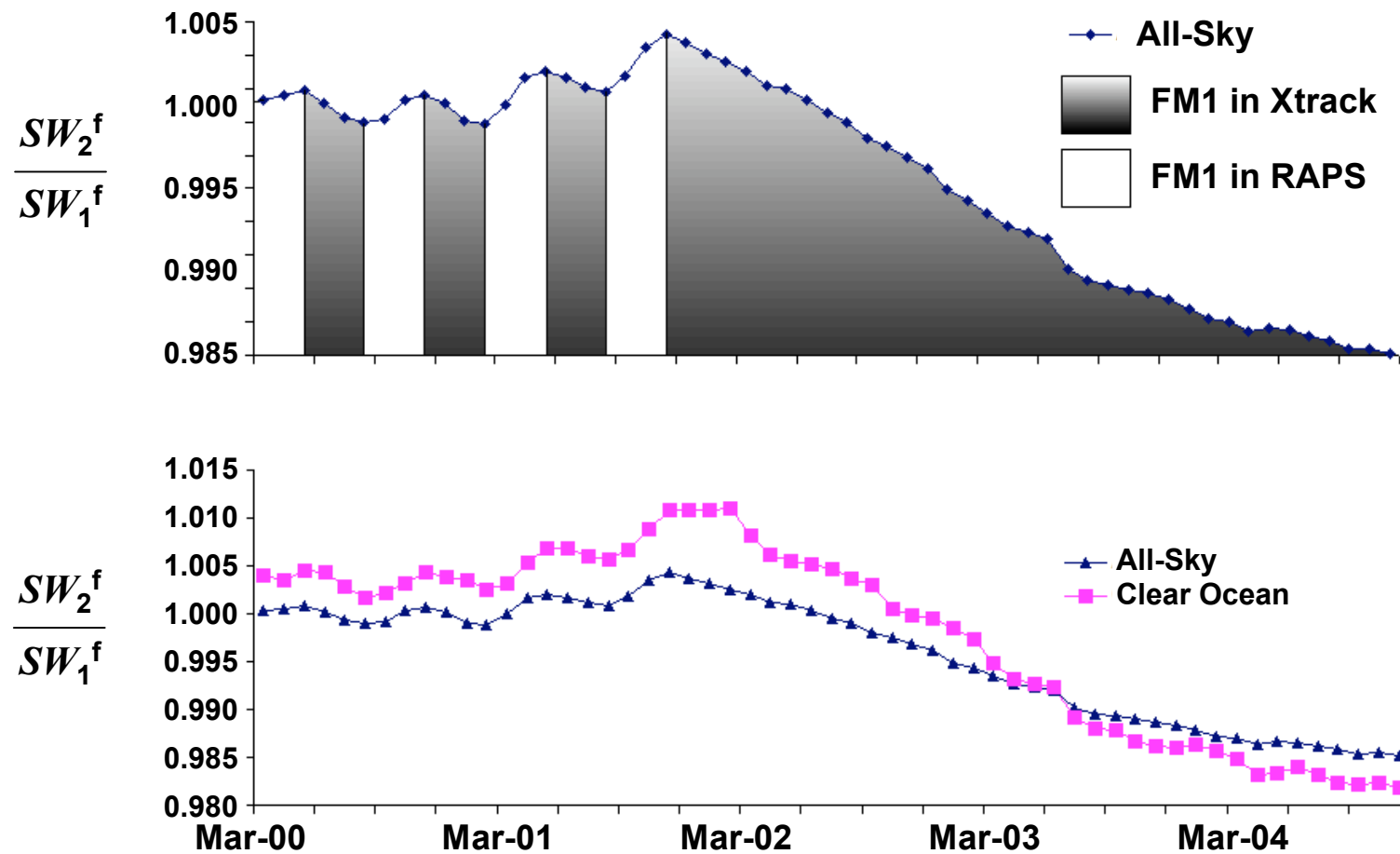
NASA Langley Research Center / Science Directorate





# Terra Edition2 Nadir Direct Comparison

## SW Nadir Radiances

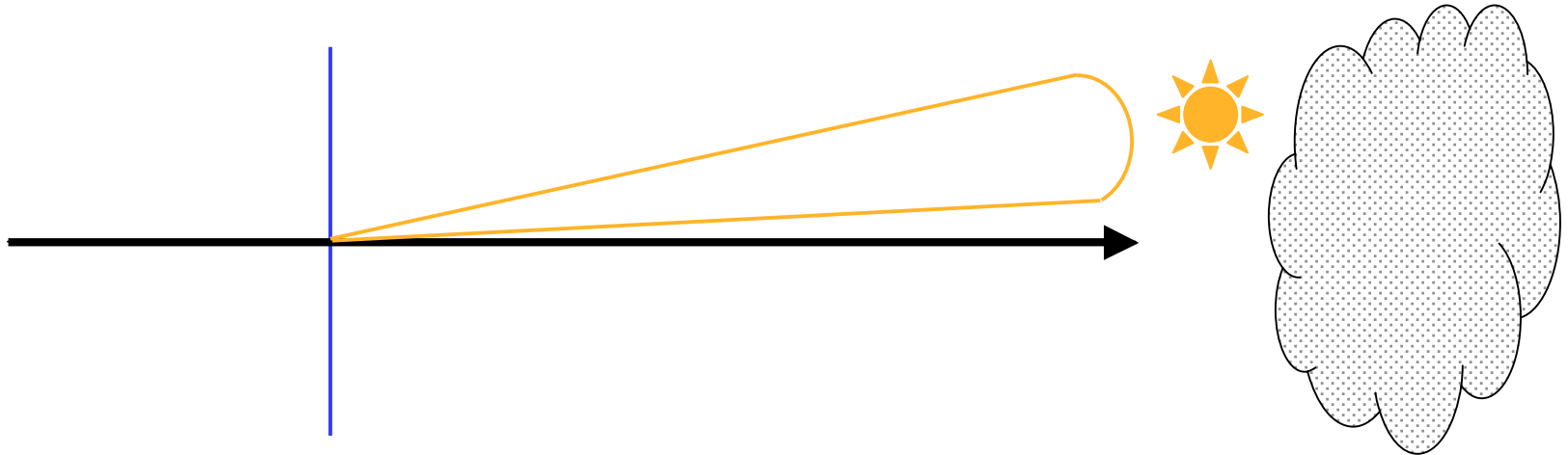


NASA Langley Research Center / Science Directorate

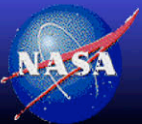
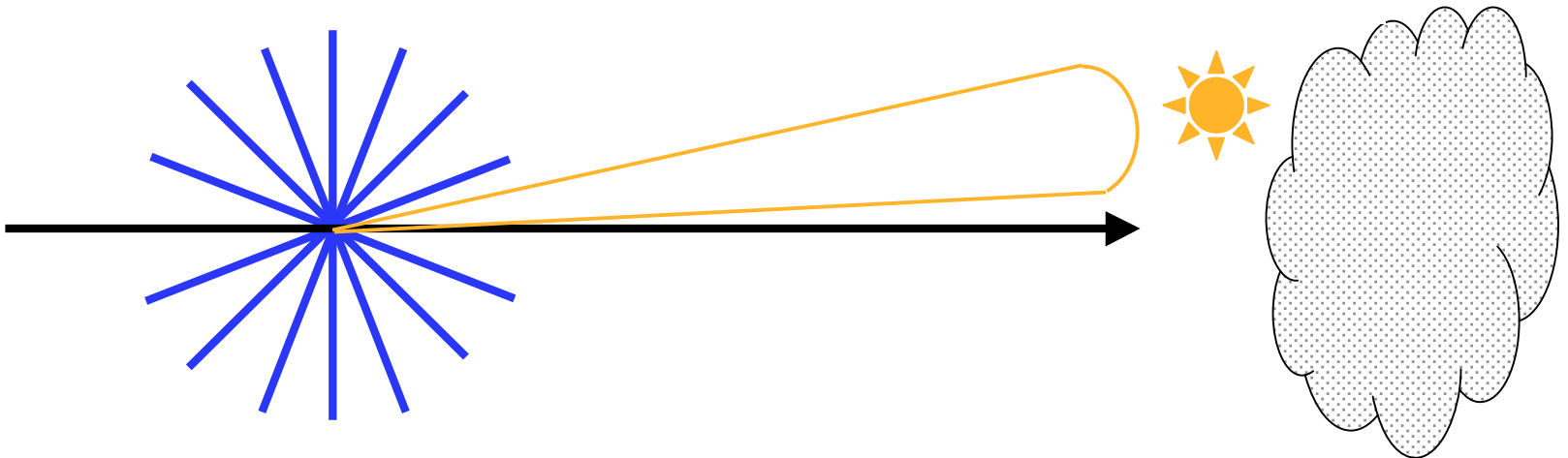


# Whats the difference between RAPS and FAPS?

**FAPS**



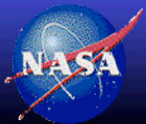
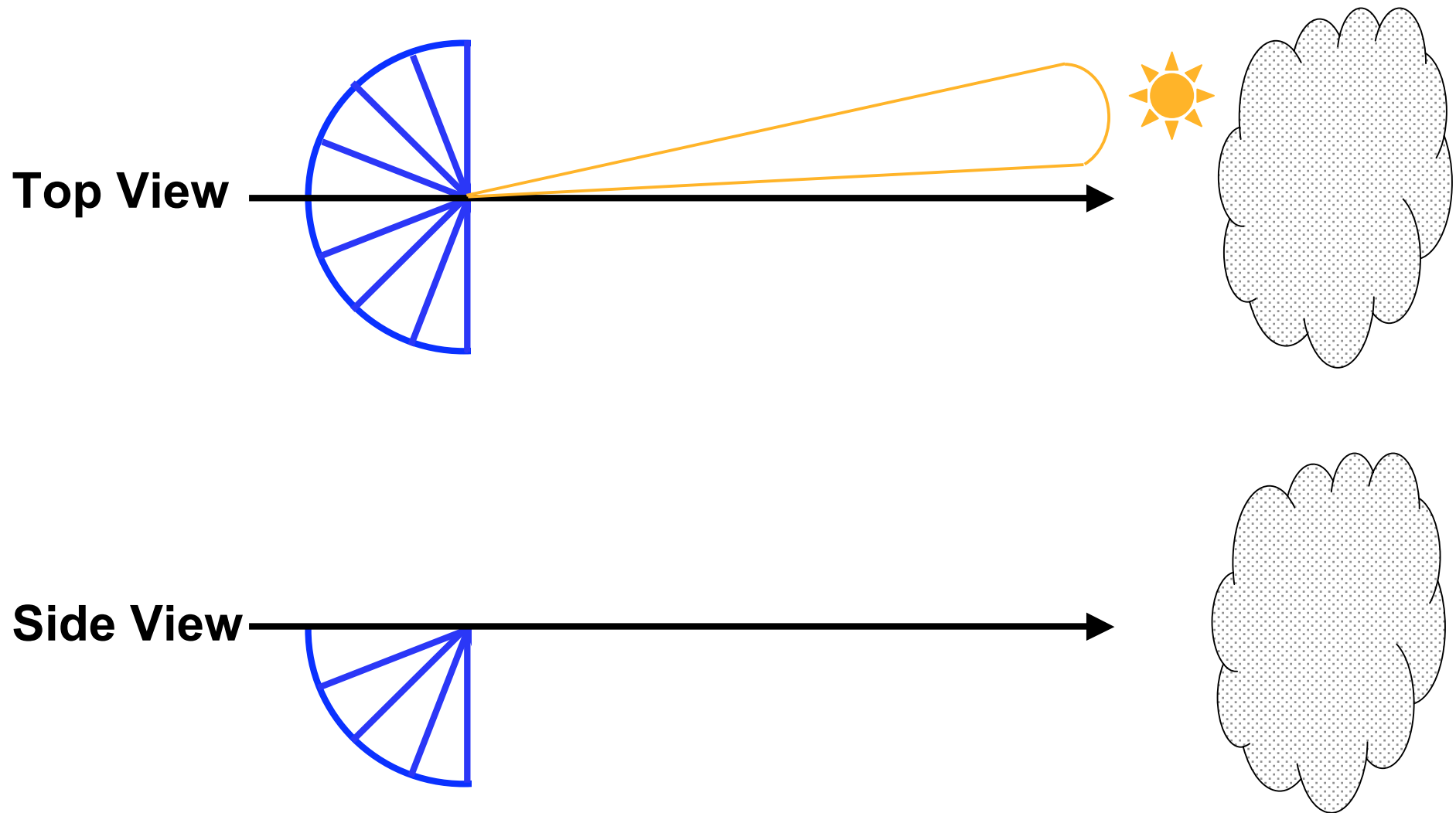
**RAPS**



NASA Langley Research Center / Science Directorate



# Visualization of new operational constraints



NASA Langley Research Center / Science Directorate





# Instrument Operations to Support Characterization

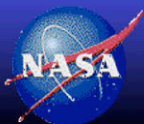
Is there evidence of active spectral darkening in crosstrack mode?

Test Platform: Terra

Operational Design: Stow one instrument while operating 2nd in Crosstrack mode.

Month	FM1	FM2
1,2	Xtrack	Xtrack
3,4	Xtrack	Stow
5,6	Xtrack	Xtrack
7,8	Stow	Xtrack
9,10	Xtrack	Xtrack

Metric: Compare matched footprints before and after stow period and test means for significance.



NASA Langley Research Center / Science Directorate

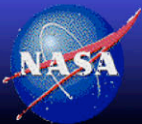
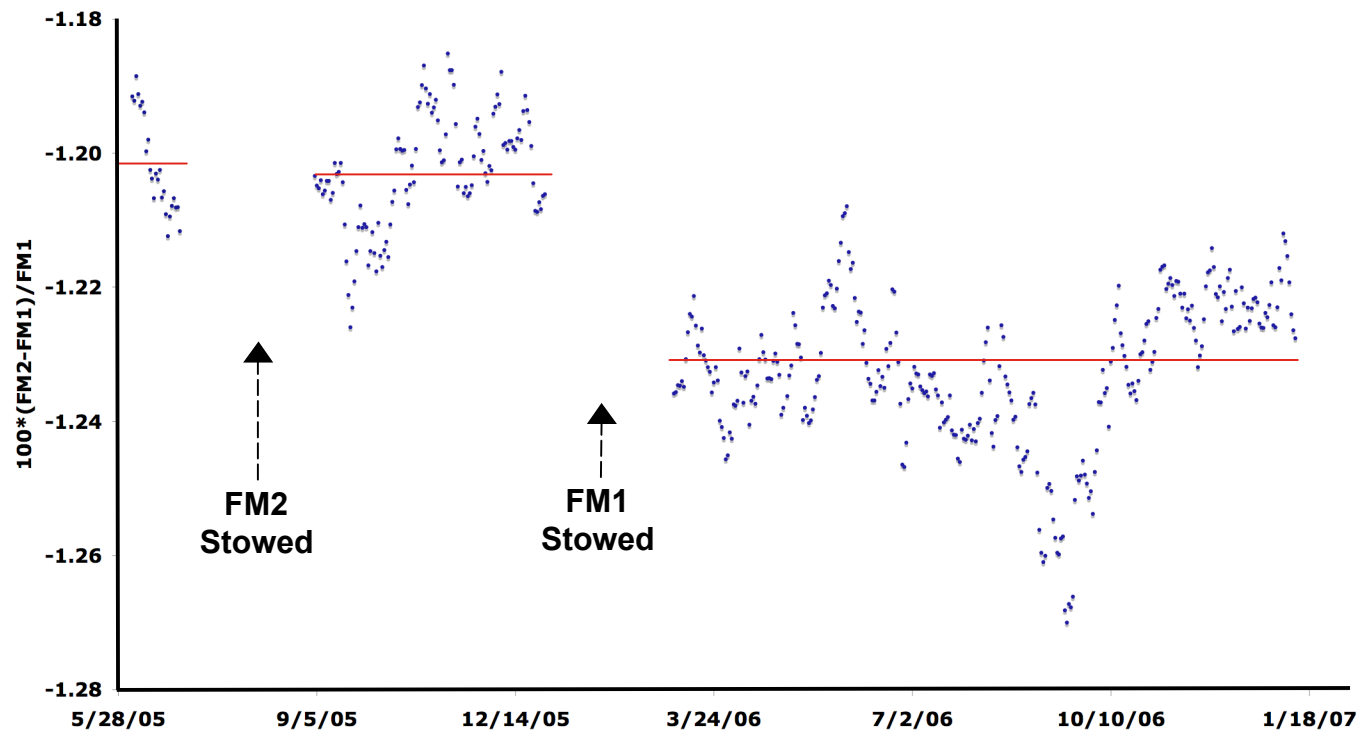


# Operations to Characterize Spectral Darkening

Year	Month	FM1 Azimuth Gimbal	FM1 Solar Calibrations	FM2 Azimuth Gimbal	FM2 Solar Calibrations	Direct Solar Exposure	RAM Direction	Darkening Rate Impact
2005	February 2005	Xtrack	Yes	Xtrack, Atrack	Yes	Nominal	Nominal <sup>7</sup>	Nominal
	March	Xtrack	Yes	Xtrack	Daily	Accelerated (FM2)	Accelerated(FM2) <sup>8</sup>	No Change
	April	Xtrack	Yes	Rotating	Yes	Reduced <sup>1</sup>	Nominal	No Change
	May	Xtrack	Yes	Rotating, Atrack	Yes	Eliminated <sup>2</sup>	Reduced <sup>2</sup>	
	June	Xtrack <sup>3</sup>	Yes	Xtrack <sup>4</sup>	No	Eliminated	Eliminated	
	July	Xtrack <sup>3,5</sup>	Yes	Stowed	No	Eliminated	Eliminated	
	August	Xtrack	Yes	Stowed	No	Eliminated	Eliminated	
	September	Xtrack	Yes	Xtrack <sup>6</sup>	No	Eliminated	Eliminated	
	October	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	November	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	December	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
2006	January 2006	Stowed	No	Xtrack	No	Eliminated	Eliminated	
	February	Stowed	No	Xtrack	No	Eliminated	Eliminated	
	March	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	April	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	May	Xtrack	Yes <sup>9</sup>	Xtrack	Yes <sup>9</sup>	Eliminated	Eliminated	
	June	Xtrack	Yes <sup>9</sup>	Xtrack	Yes <sup>9</sup>	Eliminated	Eliminated	
	July	Xtrack	Yes <sup>9</sup>	Xtrack	Yes <sup>9</sup>	Eliminated	Eliminated	
	August	Xtrack	Yes <sup>9</sup>	Xtrack	Yes <sup>9</sup>	Eliminated	Eliminated	
	September	Xtrack	Yes <sup>9</sup>	Xtrack	Yes <sup>9</sup>	Eliminated	Eliminated	
Notes: 1. Short-Earth scan profile turn-around reduced 8 <sup>0</sup> , March 31, 2005 on FM1 and FM2. 2. Expanded solar-avoidance region criteria May 13, 2005. 3. Greenland Summer Solstice Terra-Aqua Inter-Calibration, June 6- July 6, 2005 4. GERB Operations, June 9-30, 2005.						5. Nighttime internal calibrations, July 1-7, 2000. 6. Valencia Over-Flights, September 12-17, 2005. 7. Lunar Scans 8. Solar Calibrations 9. Raster Scan A_Only Azimuth Sync Profiles		

# Terra Edition1\_CV SW Full Swath Direct Comparison

Is there evidence of active spectral darkening in crosstrack mode?

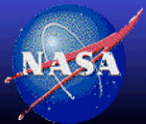


NASA Langley Research Center / Science Directorate



# Back-Up Material

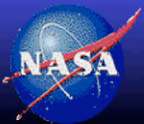
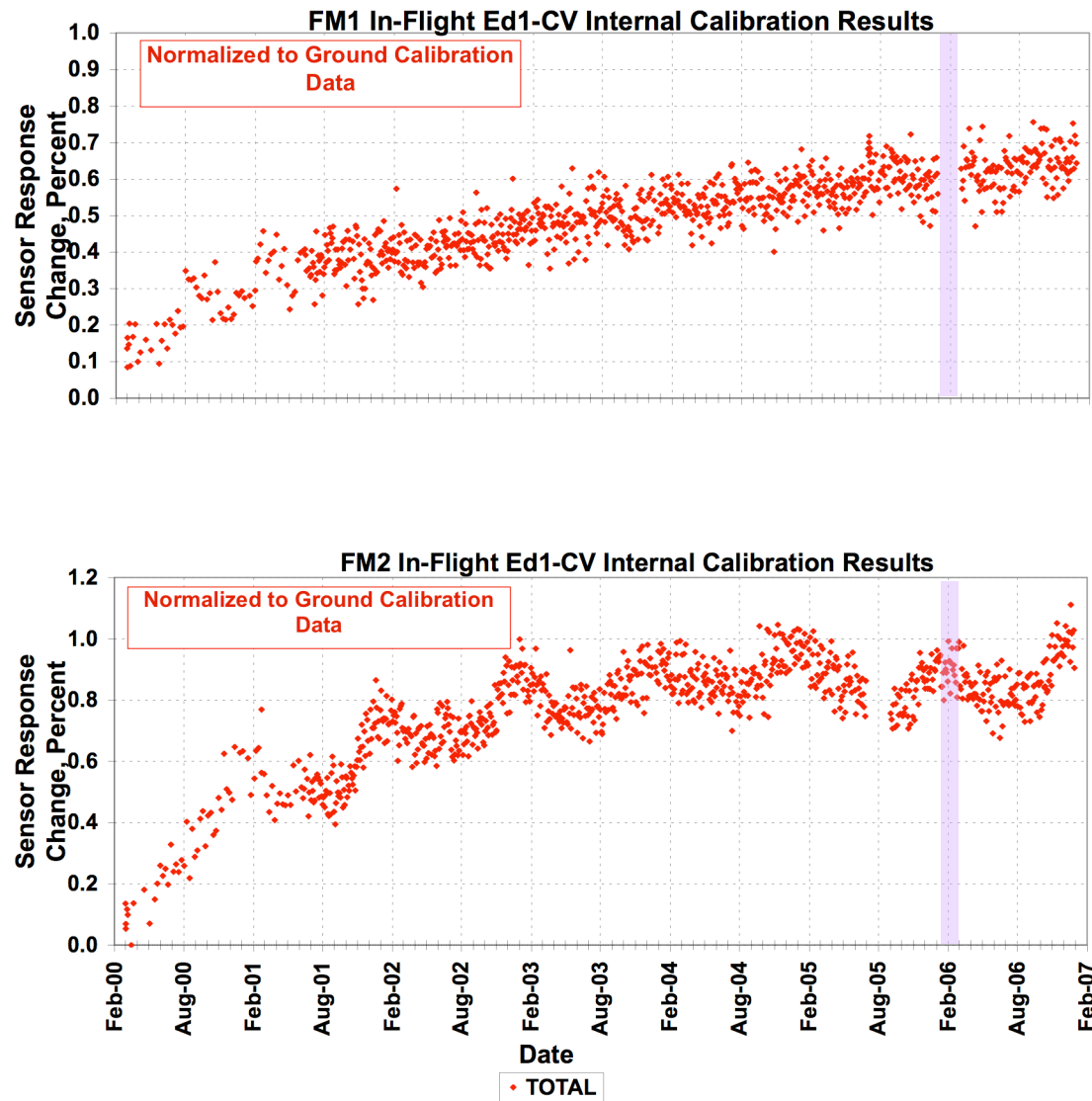
---



**NASA Langley Research Center / Science Directorate**



# Terra Edition1\_CV SW Full Swath Direct Comparison



NASA Langley Research Center / Science Directorate



# Direct Comparison of Nadir Radiance Measurements

**Two CERES instruments on a common platform allows for a unique validation opportunity.....**

## **Direct Comparison of simultaneous Nadir measurements**

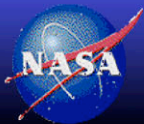
**Each CERES/Terra instrument views nadir every 3.3 seconds**

**Thus, we obtain nearly simultaneous measurements of the same geo-location ( $\Delta t < 3.3$  seconds)....**

**Spatial, angular, and temporal sampling issues are virtually eliminated.**

**26,000 co-located (but not independent) measurements in a given day, provides a very rigorous statistical tool.**

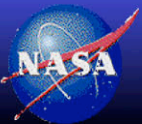
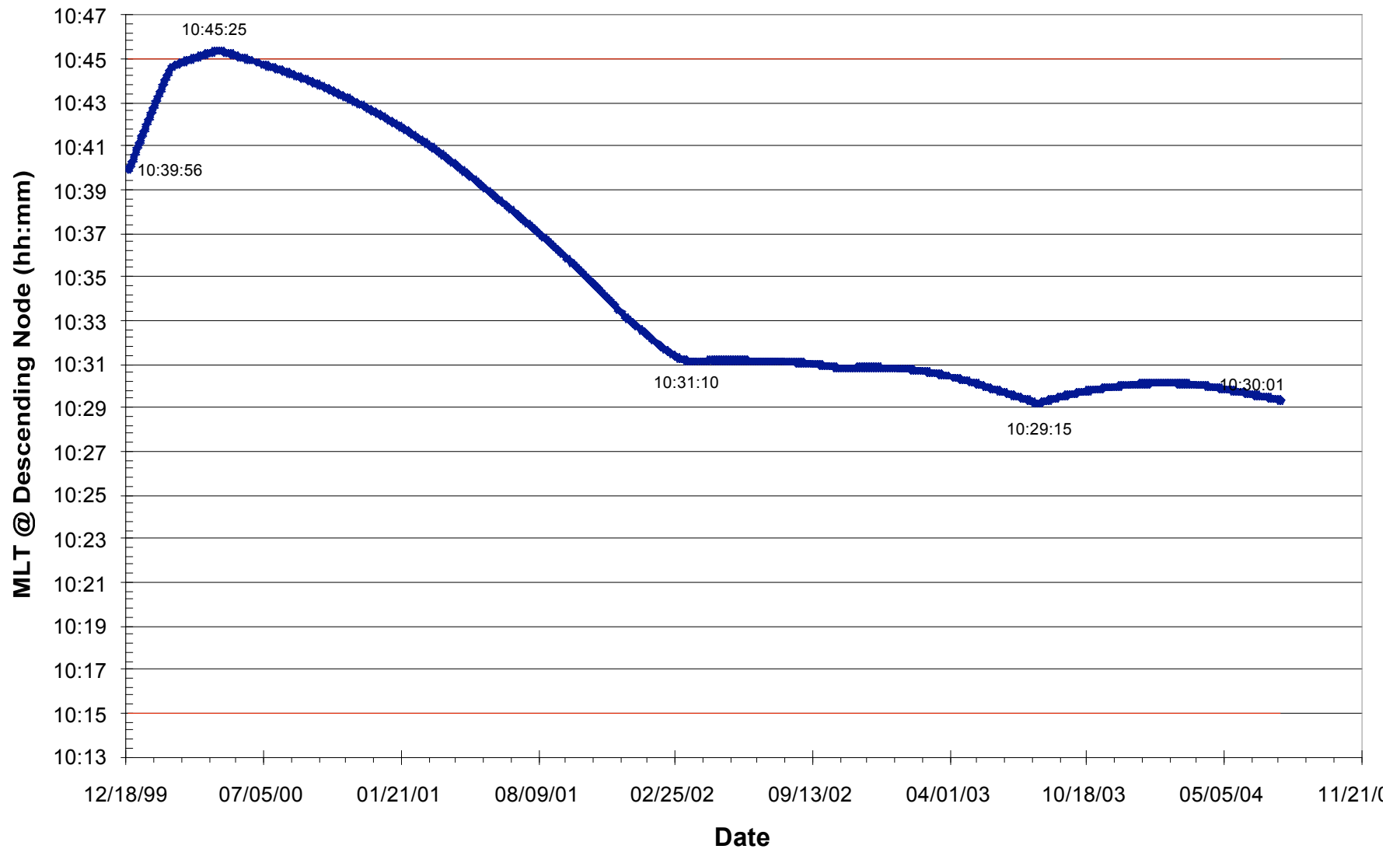
**Results can be discretized by scene type to enhance the analysis.**



**NASA Langley Research Center / Science Directorate**



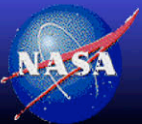
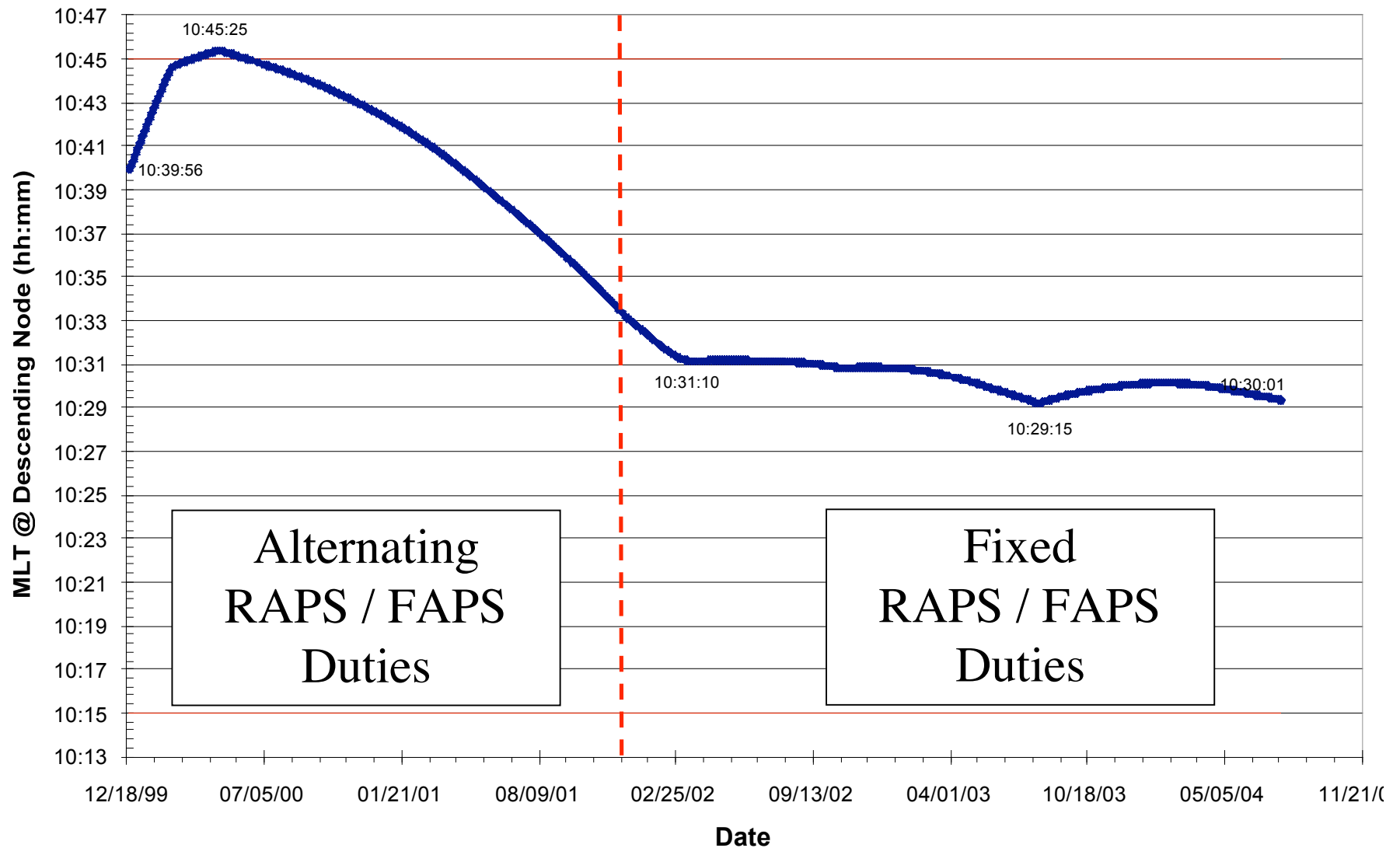
## TERRA Averaged Mean Local Time @ Descending Node



NASA Langley Research Center / Science Directorate



## TERRA Averaged Mean Local Time @ Descending Node



NASA Langley Research Center / Science Directorate





# Photochemically Enhanced Deposition

---

**UV Light can cause contamination to condense on surfaces that would otherwise remain clean**

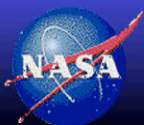
**Presumably, the UV light initiates a polymerization process that either:**

- 1) Binds the contaminant molecule to the surface,
- 2) Binds several contaminant molecules into larger molecules with a correspondingly longer residence time.

Even warm surfaces may be subject to the deposition of contaminant layers if they are exposed to solar UV

Rate of photochemical deposition of contaminants is seen to increase as the molecular arrival rate decreases. *i.e. sticking coefficient increases.*

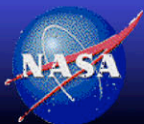
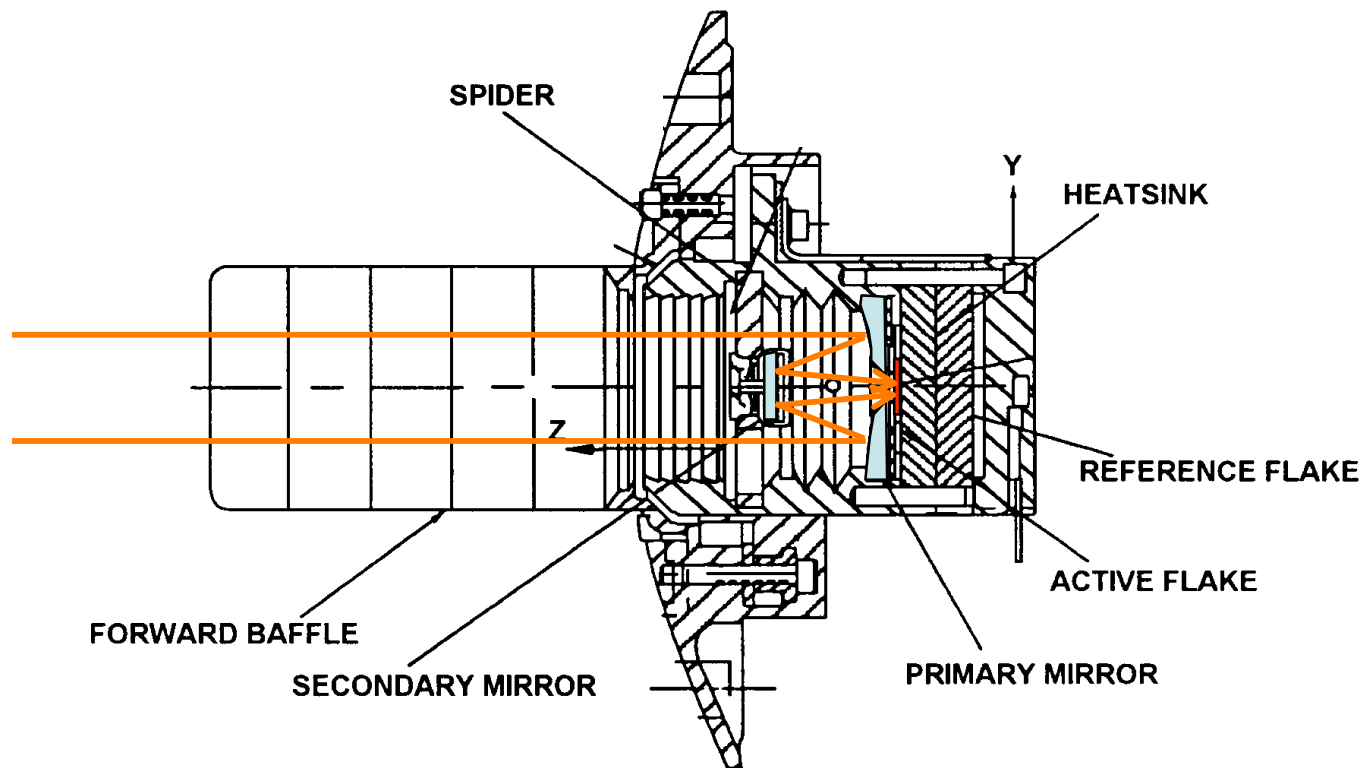
$$\text{Log SC} = -0.797 \log \text{IR} - 1.156$$



NASA Langley Research Center / Science Directorate



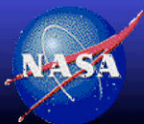
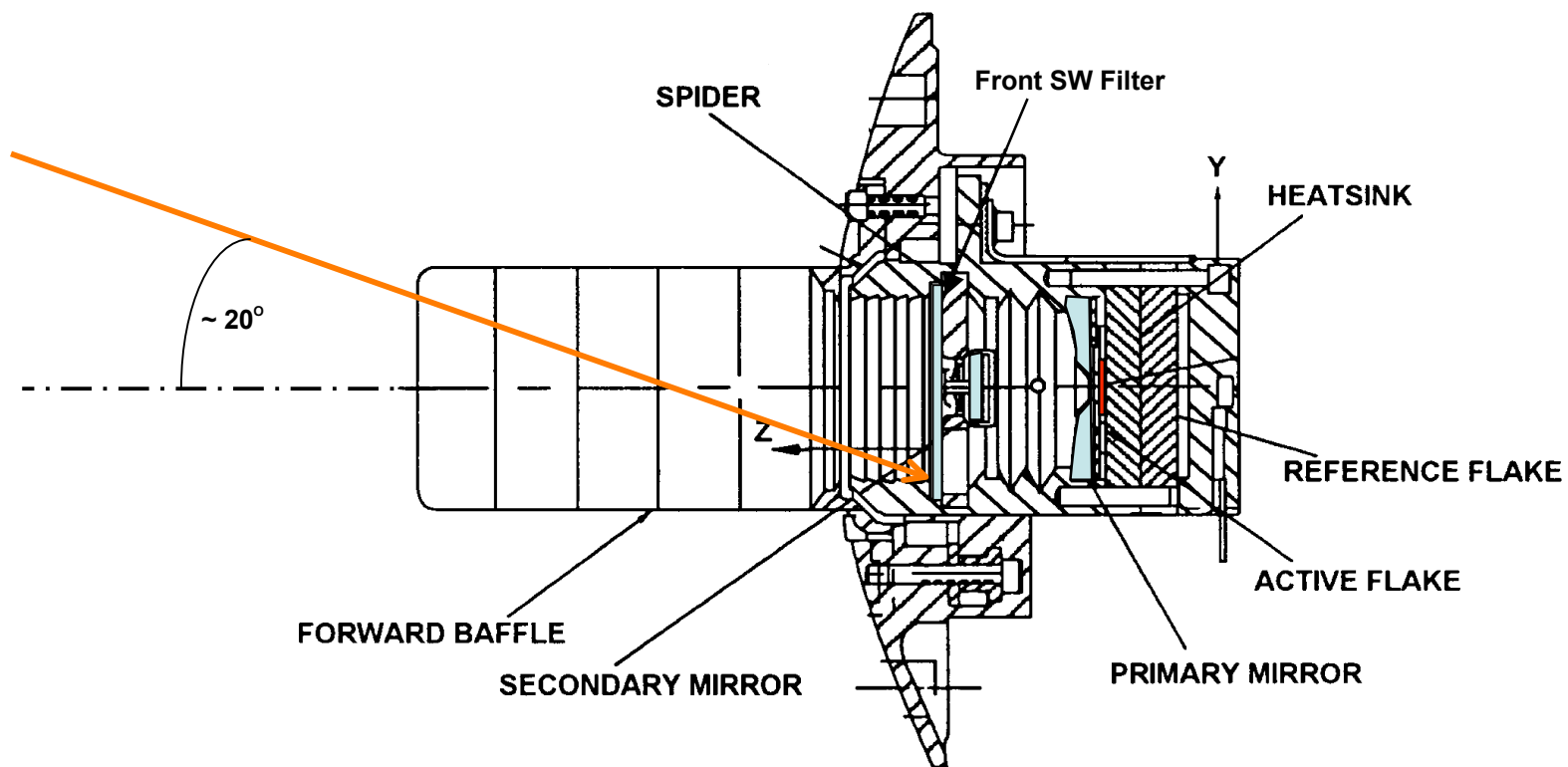
# CERES Sensor



NASA Langley Research Center / Science Directorate



# CERES Sensor

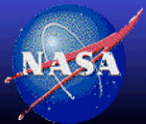


NASA Langley Research Center / Science Directorate



# BDS and ERBE-Like Release Strategy

---



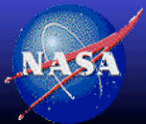
NASA Langley Research Center / Science Directorate



# Edition 3 - What is it?

---

**Edition-1-CV**



**NASA Langley Research Center / Science Directorate**



# Notification of Revision



## **CERES BDS (BiDirectional Scan) Terra Edition2 Data Quality Summary**

Investigation: **CERES**

Data Product: **BiDirectional Scan [BDS]**

Data Set: **Terra (Instruments: FM1, FM2)**

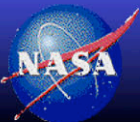
Data Set Version: **Edition2**

The purpose of this document is to inform users of the accuracy of this data product as determined by the CERES Team. This document briefly summarizes key validation results, provides cautions where users might easily misinterpret the data, provides links to further information about the data product, algorithms, and accuracy, gives information about planned data improvements. This document also automates registration in order to keep users informed of new validation results, cautions, or improved data sets as they become available.

This document is a high-level summary and represents the minimum information needed by scientific users of this data product. It is strongly suggested that authors, researchers, and reviewers of research papers re-check this document for the latest status before publication of any scientific papers using this data product.

### **Table of Contents**

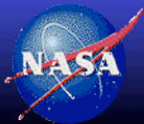
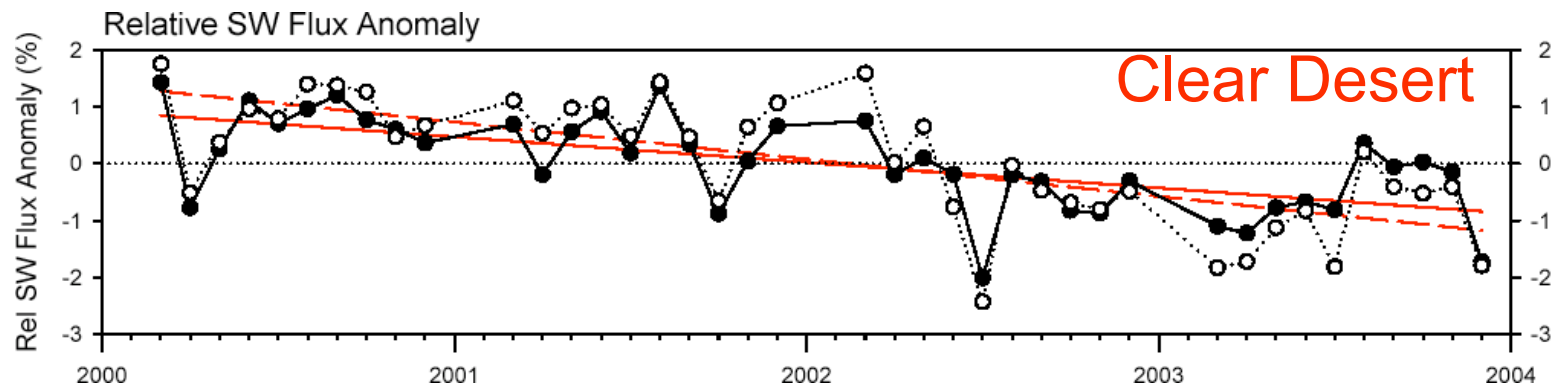
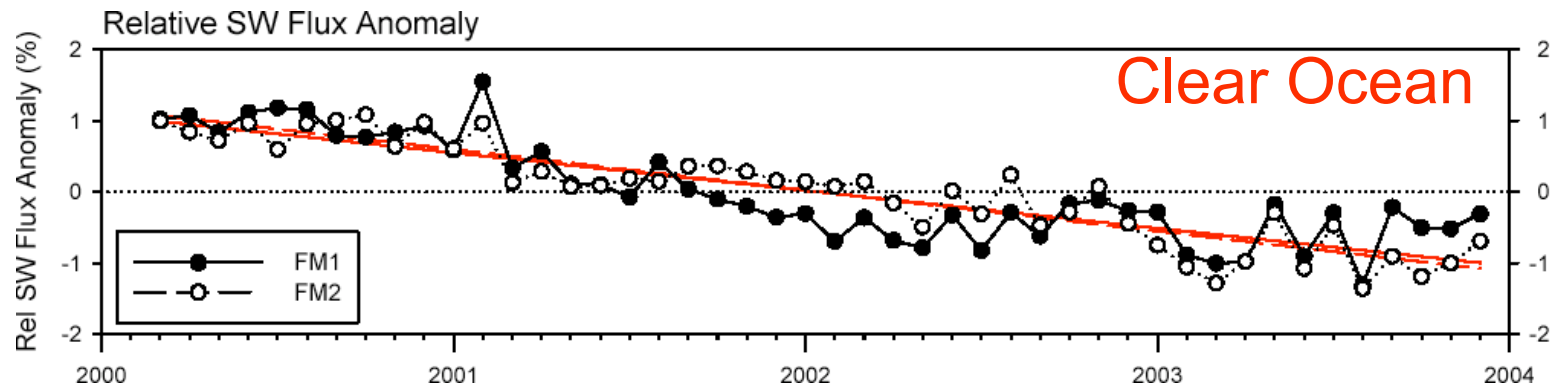
- [Nature of the BDS Product](#)
- [Updates to Current Edition](#)
- [User Applied Revisions](#)** ←
- [Validation and Quality Assurance](#)
- [Current Estimated Uncertainty of Data](#)
- [Cautions When Using Data](#)
- [Expected Reprocesings](#)
- [References](#)
- [Web links to Relevant information](#)
- [Referencing Data in Journal Articles](#)
- [Giving Data to Other Users](#)



**NASA Langley Research Center / Science Directorate**



# CERES SSF Ed2B SW TOA Flux Anomaly

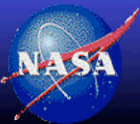
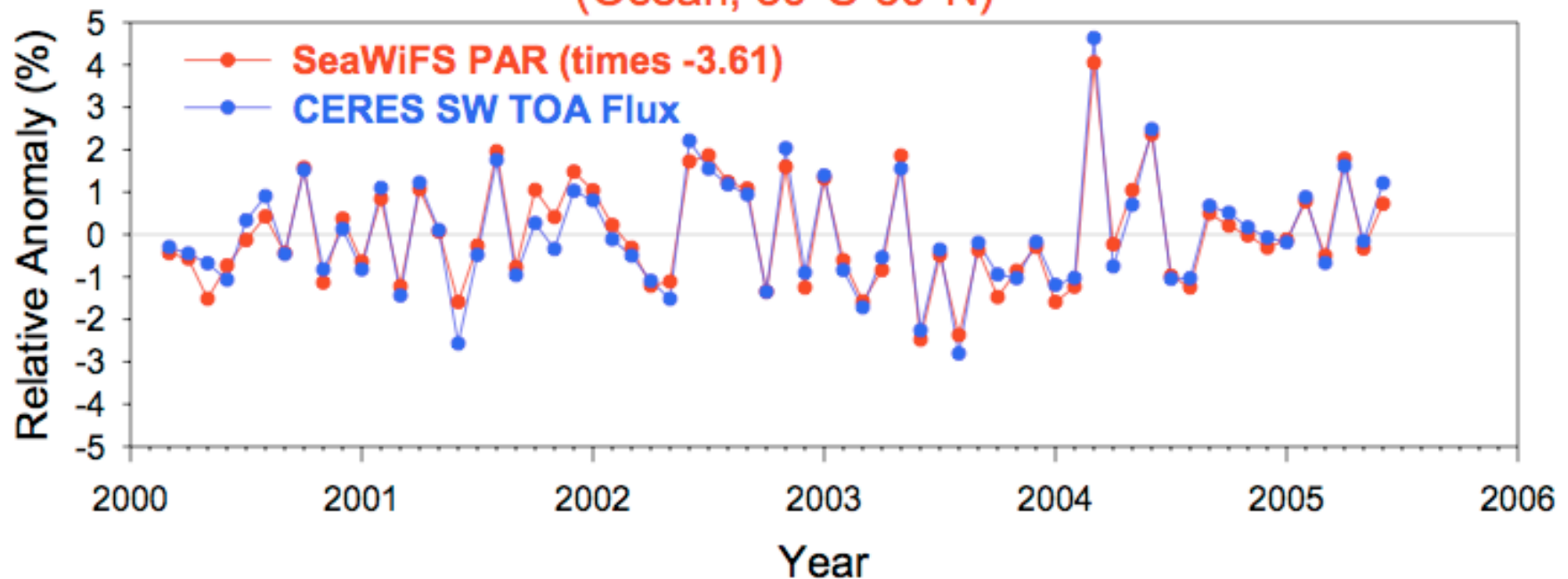


NASA Langley Research Center / Science Directorate



# Application of Edition2\_Rev1 Scaling Factors

SeaWiFS PAR and CERES FM1 Ed2B\_rev1 SW TOA Flux Relative Anomaly  
(Ocean; 30°S-30°N)



NASA Langley Research Center / Science Directorate





# Quartz Degradation Mechanisms

---

## **Charged Particle Impingement**

- Proton, electron impingement mission lifetime duration

## **Molecular Contamination**

- Thin film builds due to material outgassing
- typically decays with time
- Surface Residence Time is a function of temperature
- Build-up requires Deposition Rate > Departure Rate
- UV Exposure enhances accumulation

## **Particulate Contamination**

- Dust, predominantly pre-launch, launch

## **UV Hardening**

-

